

**DEVELOPMENT AND CHARACTERIZATION OF BRIQUETTE FROM
TANNERY SOLID WASTE**

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AUGUST, 2015.

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TANNERY SOLID WASTE**

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AUGUST, 2015.

DECLARATION

I declare that the work in this thesis entitled “Development and Characterization of Briquette from Tannery Solid Waste” has been carried out by me in the Department of Chemical Engineering, Ahmadu Bello University, Zaria, under the supervision of Dr. I. A. Mohammed-Dabo and Dr. A. O. Ameh of the Department of Chemical Engineering ABU, Zaria. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis has previously been presented for another degree or diploma at this or any other institution.

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Signature

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CERTIFICATION

This thesis entitled “DEVELOPMENT AND CHARACTERIZATION OF BRIQUETTE FROM TANNERY SOLID WASTE” by Imeh Etim ONUKAK meets the regulations governing the award of the degree of Master of Science (M.Sc) of Ahmadu Bello University, Zaria and it is approved for its contribution to knowledge and literacy presentation.

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DEDICATION

To my beloved parents Dr. E. E. Onukak (late) and Mrs. M. E. Onukak.

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My utmost gratitude is to God Almighty who has been so gracious and merciful to me. I acknowledge my loving family for all the care, love and support given to me during this phase of my life.

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I use this medium to appreciate Dr. I. K. Adamu, the Director General of Nigerian Institute of Leather and Science Technology (NILEST) and Dr. A. Ejila the Director of Directorate of Research and Development NILEST for giving me this great opportunity to achieve this academic discipline.

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ABSTRACT

The tannery industry makes use of hides and skin which are by-products of meat industry to produce leather. In the course of leather production, a huge amount of solid waste is generated. For instance, processing 1000 kg of hide will produce 870 kg of solid waste which implies that only 270 kg goes into the finished leather. The problem of the tanner is to find an economic use for the collagen and other by-products not sold as leather which are polluting the environment and posing a threat to health. This thesis was aimed at the development of briquette from tannery solid waste. The compression molding machine installed in Nigerian Institute of Leather and Science Technology, Zaria, Kaduna State was employed in the briquette production. Cassava starch was used as a binder. The elemental analysis of the raw material shows that $372,300 \pm 3,351$ mg/kg, $68,580 \pm 274$ mg/kg, $15,190 \pm 198$ mg/kg, $6,770 \pm 528$ mg/kg, $6,562 \pm 7$ mg/kg, $4,909 \pm 5$ mg/kg, $4,153 \pm 75$ mg/kg and $1,259 \pm 180$ mg/kg for Calcium Chlorine, Aluminum, Magnesium, sodium, Chromium, iron, and potassium, respectively. The briquette properties such as particle size, presence of binder, moisture content, volatile matter, ash content and calorific value were found to affect the quality of the briquettes. Briquettes with high moisture content such as 0.6844%, 1.0767% and 1.2615% had the highest calorific values of 20,140.2 kJ/kg, 22,141.3 kJ/kg and 24,101.3 kJ/kg respectively. These briquettes had in their composition high content of fleshing with a calorific value of 14,570 kJ/kg. Cassava starch used as binder had a calorific value of 159.48kJ/kg and was observed to have affected the briquette calorific value and compressive strength. The ratio of solid waste to binder were 40:60, 50:50 and 100:0. Briquettes with varying particle sizes of waste were found to be of better quality than those with uniform particle sizes. The particle sizes were 0.5 mm for fleshing, chrome shavings and buffing dust, and 1.0mm for hair. Briquettes with compressive strength of

0.2173 kN/cm², 0.1910 kN/cm² and 0.1742 kN/cm² were found to be more durable with durability of 99.23%, 99.27% and 99.77% respectively. The briquette without binder was the least durable by 98.12% even though it had the highest calorific value of 24,101.3 kJ/kg. The economic analysis shows that the production of briquette from tannery solid waste was feasible and also viable. Briquette production plant with 8460 tons capacity will require a total investment of ₦3,732,056 and pay-back period will be within five years at the rate of about 19% per year. Acceptability survey showed that in Hayin Danyaro and Zango, Samaru, Kaduna state, 96% of female respondents and 86% of male respondents were willing to switch over to using fuel briquettes to meet their cooking and heating needs.

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ABBREVIATIONS

TDB	Tannery Derived Briquette
ULW	Unique Leather Waste
CHP	Combined Heat and Power plant
TSW	Tannery Solid Waste
BOD	Biological Oxygen Demand
ULF	Unique Leather Finishing Company
HR	Hair
FL	Fleshing
CS	Chrome Shavings
BD	Buffing Dust
PMC	Percentage Moisture Content
PVM	Percentage Volatile Matter
PAC	Percentage Ash Content
PFC	Percentage Fixed Carbon
TFE	Thermal Fuel Efficiency
SEM	Scanning Electron Microscope
NAA	Neutron Activation Analyser
NIRR-1	Nigerian Research Reactor 1

HPGe	High Purity Germanium Detector
FC	Fixed Capital
WC	Working Capital
VC	Variable Cost
TI	Total Investment
TPY	Tonne per Year
PPC	Physical Plant Cost
PEC	Purchase Equipment Cost
APC	Annual Production Cost
AP	Annual Profit
PBP	Payback Period
ROR	Rate of Return
ROI	Return on Investment
ABU	Ahmadu Bello University
NILEST	Nigeria Institute of Leather and Science Technology
CERT	Centre for Energy Research and Training

CHAPTER ONE

1.0 INTRODUCTION

Biomass is one of the most common and easily accessible renewable energy resources and represents a great opportunity as a feedstock for bioenergy. A wide range of biomass resources - crop residues (corn stover, rice husk, etc.), wood wastes from forestry and industry, residues from food, leather and paper industries, municipal solid wastes and dedicated energy crops such as short-rotation perennials can be utilised to generate electricity, heat, combined heat and power, and other forms of bioenergy (Akowuah, 2012).

Briquetting is a densification method use in the conversion of solid biomass into fuels. Biomass briquettes are ready substitute of coal or wood in industrial boiler and brick kiln for thermal application. They are non-conventional source of energy, renewable in nature, eco – friendly, non-polluting and economical. The densification of biomass can produce densified briquettes with uniform shapes and sizes that can be more easily handled using existing handling and storage equipment and thereby reduce cost associated with transportation, handling, and storage (Karunanithy, 2012). A uniform structure can also facilitate breathability and make less of a biomass bridge. These advantages improve the system's ability to maintain a stable and efficient operation. This fledgling biomass fuel industry's impact in the economy is currently relatively weak; levels of production do not make up even a fraction of the total usage of biomass fuel. Looking forward, it is foreseeable that existing and new producers will expand operations similar to the current model (production of charcoal dust briquettes) and briquette use could displace up to 5-10% of present charcoal consumption which enhances deforestation and global warming. A diversification of feedstock, from charcoal dust to agricultural, municipal and industrial wastes like TSW (available in larger quantities) would allow the industry to scale up and have a higher impact on sustainability.

Leather is used to produce a variety of finished goods ranging from; shoes, bags, clothing, belts, furniture, stuffed animals, puffs, wrist watch straps, mats, wallets, footballs, accessories etc. The process of converting hides and skin which are by-products of meat industry into leather is referred to as tannery. The industry was estimated to contribute about 140 million dollars to the total income revenue of the country (USAID, 2002). This made it the third highest income revenue next to oil and cocoa. Currently, there has been a drastic rise to 680 million dollars (Aganga, 2013) thus displacing cocoa as second place in highest income revenue of Nigeria (Nimerbeh, 2014). Good as that may be, the conventional leather tanning technology generates large amount of organic and chemical pollutants.

The solid waste generated during leather processing is highly significant. Whilst the leather industry is making use of the by-product from the meat industry, only 20% of the raw material ends up in the finished leather (Addy, 2004). According to conservative estimates, about 600,000 tons per year of solid waste are generated worldwide by leather industries (Salman, 2012). Tannery waste can be viewed as a valuable resource. This can be either as a substrate for the production of value added products or as a fuel (Addy, 2004). The generation of energy from biomass gained attention in reference to increasing usage of renewable energy resources which provides independence from imported energy and reduction of fossil fuel use. Substitution of fossil feedstock for energy by biomass is an important measure also for greenhouse gas (GHG) emission mitigation (Edger *et al.*, 2011).

Leather production in accordance with “best energy use practises” will require 30kW of energy per hide (BLC, 2010). From investigation, it has been concluded that, depending on the waste streams and the blend of materials, sludge and buffing dust will produce approximately 1kw/h of energy per 1kg of waste (BLC, 2010). In particular, tannery derived briquette (TDB), obtained from Unique Leather Waste (ULW) pre-treated from

sludge and solid waste could be considered as feed stock for gasification to produce heat and electricity. This will aid the tannery to be self-sustaining in terms of energy.

Biomass gasification technology is not so well established as that of large scale coal or petrochemical residues. However, the wood industry in USA obtains more than half of its electricity and thermal energy from biomass. Even in 1996, the capacity in this sector alone was 7 GW or approximately 20% power generating capacity in Mexico. Biomass gasification is set to grow in the future through the provision of de-centralised power for niche markets such as leather or paper manufacture (BLC, 2010).

Unique Leather Finishing Co. Ltd, Sharada-phase 1, Kano is the case study for this research and the raw materials were collected from this tannery. It has been in business for 35years. The tannery has grown in accordance to the demand of the leather and financial resources of the company. Production is seasonal and installed capacity is approximately 1,500,000 pieces of skins per year. This comprises mainly of sheep and goat skin. Average production is 25,000 pcs of skin and 50-200 pcs of hides daily. Sheep and goat skin are processed into leather, hides as crust for export and local market. The tannery employs approximately 300 workers (UNIDO, 2004). It produces finished garment leathers, sports gloving leather from sheep skin, finished goat suede for shoe upper, finished cow hide for shoe upper, finished crust lining leather and cow hide crust. From statistic, the industry generates about 4.711 tons of waste from raw hides in the process of leather tanning and 10 tons from skin. Making a total of 14.711 tons of solid tannery waste daily.

1.1 PROBLEM STATEMENTS

One of the emerging problems faced by the world today is management of all types of waste and energy crises. Different forms of solid waste such as hair, fleshings, splits,

trimmings, shavings and buffing dust which emerge during the transformation of hides and skins into leathers have negative impacts on the environment.

The contemporary option for the disposal of these wastes is by landfill which may become cost prohibitive in the future and possess a lot of challenges due to unfavourable policies and regulations.

The problem for tanners is to find an economic use for collagen and by-products not sold as leather. In order to overcome this problems, there is a need to explore more on the utilization of the waste into heat and power generation.

1.2 AIM AND OBJECTIVES

With the incentive of controlling rising waste disposal costs and the constant threat of tightening environmental legislation, there has been a considerable amount of research into alternative waste disposal routes. This research, considers one important way of treating leather waste to produce fuel particularly for gasification process. This can be achieved through the following objectives;

1. Collection, Pre-treating and Characterization solid waste pollutant generated from the tannery.
2. Production of briquette from the Pre-treated Tannery Solid Waste (TSW).
3. Characterization of the briquette produced for optimum fuel properties and economic value.

1.3 JUSTIFICATIONS

Converting tannery solid waste into briquette will bring about the following;

1. Reduction in environmental pollution and health hazard.
2. Innovation to the local content by processes of densification and gasification.
3. Reduction in operational cost by making the tannery energy self-sustaining.
4. Creation of job as skilled and unskilled labour will be employed in the process.
5. Generation of income as both heat and electrical energy produced could be commercialised to sustain small business.
6. Provision of a renewable and sustainable fuel.

1.4 SCOPE

This research is limited to;

1. The conversion of tannery solid waste (TSW) to a biofuel by producing TDB in an attempt to simultaneously address waste management and energy crises.
2. Characterisation of the briquette produced for physical, chemical and mechanical properties.
3. To compare and ascertain the viability of the briquette produced from raw tannery solid waste and the carbonised tannery solid waste as well with application of binders.
4. Economic valuation of the tannery derived briquette will also be carried out via economic analysis.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 TANNING INDUSTRY IN NIGERIA

There are 41 commercial tanneries in Nigeria, with a collective installed production capacity of 310,000 hides and 25.5 million pieces of skin per annum. It is interesting to note that local tanneries supply less than 10% of the national demand for leather by the shoe-manufacturing sector. Currently only sixteen of the 41 tanneries are functional. Twelve of the 41 are designed to produce finished leather and wet blue; only eight are still in operation. Twenty-nine of the 41 tanneries produce wet blue only. Out of this number only eight are functional (USAID, 2002). Plate 2.1 shows a finished processed goat skin into a premium quality leather.



Plate I: Premium quality leather made of Nigerian goatskin.

Most of the tanneries in the country are predominantly based in Kano. Many of functional tanneries are foreign owned, and have a mandate to export high quality leather, with the rest sold to the domestic market. While the government has prohibited the export of untanned hides and skins and wet blue, export trade in such commodities still exists but is declining (USAID, 2002).

Unique Leather Finishing Company (ULF) Ltd. Is a tannery located at 55/62 Sharada

Industrial Estate Phase-One, Kano, Nigeria, employs approximately 300 workers and has an installed capacity of 50 tons per day (achieved during peak season) with average production of approximately 15 tons per day. The industry processes sheep and goat skins for export from raw up to crust and hides from raw up to finish for local market (UNIDO, 2004).

2.2 TANNERY SOLID WASTE

The conventional leather tanning technology is highly polluting as it produces large amounts of organic and chemical pollutants. Wastes generated by the leather processing industries pose a major challenge to the environment. According to conservative estimates, about 600,000 tons per year of solid waste are generated worldwide by leather industry and approximately 40–50% of the hides are lost to shavings and trimmings (Salman, 2012).

In 1997, Nigeria produced 27,000 tons of cattle hides, a level that has remained relatively static since. The production of sheep skin, on the other hand, increased from 2,800 tons in 1995 to 5,000 tons in 2002, while the production of goat skin rose from 10,200 tons in 1995 to 12,200 tons in 1996 and has remained relatively static since (USAID, 2002). From processing 1Ton of hides, waste of 0.85Tons is generated (Sandeep *et al.*, 2010). From the statistic above it could be estimated that the average solid waste generated from tanneries in Nigeria per annum is about 500 tons. In some part of the country, particularly those from the South, hides and skins when properly prepared are considered a delicacy among certain populations. Though it is difficult to estimate the volume demanded for food, it is clear that a significant proportion of the production is consumed as food (USAID, 2002). This has generated a challenge to the industry as the raw material is competing for food even though it is alleged to have no significant nutritional value.

Table 2.1: Estimated amount of solid (protein, tanned and untanned) waste during the processing of 1 ton of salted hides according to various authors.

	Püntener	Alexander	Buljan
Untanned Waste:			
Shavings Subepidermal	530 kg	120 kg	100 kg
Tissue Trimmings	135 kg	70-230 kg	300kg
Tanned Waste:			
Shavings	145 kg	100 kg	99 kg
Split		115kg	107kg
Dyed and Finished Waste:			
Shavings	10 kg	32 kg	10 kg
Fluff		2 kg	1 kg
Total	870 kg	439-599 kg	637 kg

Source: Ozgunay *et al.*, 2007.

Everyday a huge quantity of solid waste; trimmings of finished leather, shaving dusts, hair, fleshing, trimming of raw hides and skins, are being produced from the industries. Chromium, chlorine, sulphur, oils and noxious gas (methane, ammonia, and hydrogen sulphide) are the elements of liquid, gaseous and solid waste of tannery industries (Sandeep *et al.*, 2010).

Approximately a skin weighs 1kg while hide is about 14kg but this is dependent of the type of breed or specie. Table 2.1 represents the various type and amount of solid waste generated in the course of processing 1 ton of hide by different authors. Solid wastes in leather processing are constituted from; beam house-80%, tanning-19%, and finishing-1%. During the tanning process at least 300 kg of chemicals (lime, chromium, salt etc.) are added per ton of hides. Excess of non-used chemicals will appear in the waste which pollutes the environment if not properly disposed. Because of the changing pH, these

compounds can precipitate and contribute to the amount of solid waste or suspended solids. Every tanning process step, with the exception of finishing operations, produces wastewater. An average of 35 m³ is produced per ton of raw hide. The wastewater is made up of high concentration of salts, chromium, ammonia, dye and solvent chemicals etc. (Sandeep *et al.*, 2010).

Solid waste generated in tannery industry

1. Fleshing; 56%-60%
2. Chrome shaving, chrome slit and buffing dust; 34%-40%
3. Skin trimming; 5%-7%
4. Hair; 2%-5% (Sandeep *et al.*, 2010).

Data gotten from Unique Leather Sharada, Kano, reveals that 25 tons of skins and 7 tons of hides are processed daily (UNIDO, 2004) and from review it has been established that from 1 ton of hide, 850 kg of solid waste is generated. Also from 1 kg of skin, 0.6 kg of waste is generated (Ozgunay *et al.*, 2007).

Hence approximately, 4.711 tons of waste is generated from raw hides in the process of leather tanning and 10 tons from skin. Making a total of 14.711 tons of solid tannery waste daily. TSW are generated at different leather production units as shown in Plate 2.2 from processing sheep skin.



(A) Raw skin



(B) Fleshing



(C) Hair



(D) Chrome shavings



(E) Buffing dust

Plate II: Solid Waste Generated from Processing Sheep Skin

2.2.1 Tannery Solid Waste Generation

Tannery solid waste are generated from the three tanning operation units;

2.2.1.1 Beam house operations

The stages in leather production between curing and tanning are collectively referred to as

beam house operations. They include; soaking, liming, removal of extraneous tissues (unhairing, scudding, and fleshing), delimiting, bating (including puering), drenching, and pickling. The solid waste generated at this stage is the hair/fur, nail skin trimming and other keratinous matter (flesh). Over 80 per cent of the organic pollution load in BOD terms emanates from the beam house (pre-tanning); much of this comes from degraded hide/skin and hair matter (Salman, 2011).

2.2.1.2 Tanning unit

In this unit, vegetable or mineral tannins are bound to the collagen proteins in the hide and causing them to become less water-soluble, and more resistant to bacterial attack. The process also causes the hide to become more flexible. TSW generated at this stage include; chrome shaving, chrome slit and buffing dust.

2.2.1.3 Post tanning/finishing unit

In this stage, retanning agents and dyes are added to the material to provide the physical strength and properties desired depending on the end product. Also, if so desired, finishing materials are applied to the surface. The TSW generated at this stage is leather trimmings.

2.2.2 Effects of Tannery Solid Waste

Solid wastes generated from tanning industries contain different chemicals which were used during leather manufacturing process. These tannery solid wastes have different characteristics as different chemicals and mechanical processes are applied to the raw hides/skins. If these solid waste generated during various tanning operations are not properly utilized or disposed they are likely to cause a number of problems on the environment. If salt dust or de-dusted salt from preserved hide or skin is heap up outside the tanneries or dumped in open dumping area, it is likely to be washed away during rains and cause groundwater pollution. Discharging hair waste and lime sludge wastes along with the effluents causes choking of drains. Raw and green fleshings, limed fleshings, splits

(splitting waste) and trimmings putrefy easily and give rise to noxious smells. In many tanneries, it is the foul odour which emanate from some of these putrescible solid wastes which accounts for much of the smell traditionally associated with tannery wastes. Some of the bio-degradable tannery solid wastes are sources of pathogenic bacteria and volatile organic compounds emission. As leather industries mostly use chrome sulphate for leather manufacturing process, some of the solid wastes generated from the industry contain chromium (Cr) which is one of the toxic heavy metals and known for contaminating ground water, soil, plants and causing carcinogenic effect on human health. The standard safe limit for chromium metal in the soil is 150ppm (Abajihad, 2012).

2.3 CHARACTERISATION OF TANNERY SOLID WASTE

2.3.1 Chemical Composition of Waste

The chemical composition of solid wastes generated from beamhouse operations (fleshings, trimmings, splits) depends mainly on the type and quality of the raw material, treatment type and process conditions. The main components of the waste are organics comprising mainly of proteins and fat, up to 10.5% (w/w) for both groups. Water content is high: moisture amounts to 60%. These wastes contain small amounts of mineral substances, 2-6% (w/w). Chromium compounds are not present in the material (DRYWASTE, 2011).

The tanned leather wastes are mainly useless splits, shavings and trimmings. These waste groups differ mostly in size and shape, the chemical composition is comparable for each. They contain 3-6% (w/w) of fat and about 15% (w/w) of mineral components, including 3.5-4.5% (w/w) of chromium as Cr₂O₃. Sludge from wastewater treatment plants contains mostly water (up to 65% (w/w)), organic substances (30% (w/w)) and chromium (III) compounds (about 2.5% (w/w)) (Famieles and Wieczorek-ciurowa, 2011). These total

chromium values, greater than 3g/kg and below 5%, render these waste types non inert and non-hazardous according to Portuguese law (Decreto-Lei, 2002).

Some research work on tannery sludge shows that the level of chromium content is 500 mg/kg and this is five folds higher than that should be present in the soil (100 mg/kg). It has moisture content (60.6%), pH (7.4), Organic Carbon (20%), Total kjeldhal nitrogen (1.0) and carbon to nitrogen ratio (20). Due to the low solubility of chromium, only a little (Cr) is bioavailable, which means that even when crops are grown in soils treated with sludge relatively high in Cr, phytotoxicity is rarely observed (Abajihad, 2012).

2.3.2 Scanning Electron Microscopy

The Scanning Electron Microscopy is a method which is often used for the investigation of leather, collagen or plastic/polymer substances to determine their topography, morphology, composition and crystallographic structure. If light microscopy is insufficient. Particularly, SEM is used if higher resolutions are needed. The qualities that distinguish scanning electron microscopy from other methods includes large depth of field and high-contrast images of surface structures. Also the investigation of very dark surfaces or transparent materials is very favourable by using SEM technique. The SEM requires an electron optical system to produce an electron beam, a specimen stage to place the specimen, a secondary-electron detector to collect secondary electrons, an image display unit and an operating system to perform various operations. The electron optical system consist of an electron gun, a condenser lens, an objective lens to produce an electron beam and other components. The specimen is irradiated with a fine electron beam. Secondary electrons are emitted from the specimen surface. The results are observed by two-dimensional scanning of the electron beam over the surface of the specimen and the image acquired is displayed on the monitor. Plate 2.3 c and f shows the SEM of chrome shavings and buffing dust respective at 2.0 kV, 50.0 magnification and at a point with diameter of 600nm.

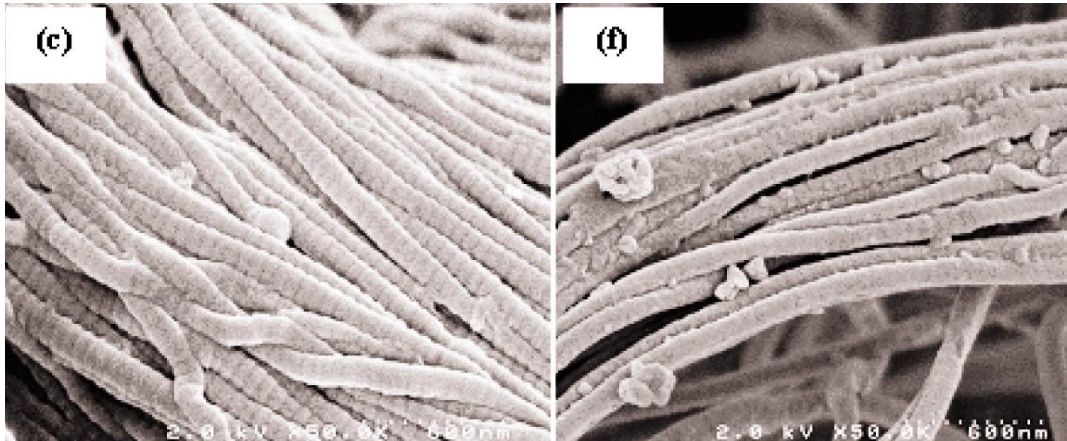


Plate III: SEM of TSW (C) Chrome Shaving and (f) Buffing Dust

Source: (Tahiri, *et al.*, 2003)

2.3.3 Thermal Fuel Efficiency of Fuel (TFE)

This is a function of the material thermal property, thermal conductivity, thermal conductivity heat capacity, heat diffusivity and temperature gradient. “Efficiency” in heating is not, of course, how much heat is produced, it is how much heat energy is produced in proportion to how much fuel energy is put in, usually expressed as a percentage. There is only a certain amount of heat which can be released from fuel by burning it, roughly 7kW in each kg of coal and 5kW in each kg of dry wood (SOLIFTEC, 2015). Heat is transferred via conduction, convection, radiation and volatile flow of gasses. The 'net' efficiency figure applied to solid fuel appliances doesn't account for the heat wasted in boiling off the water in the fuel. It is a bit difficult to calculate (shaka, 2013). Factors effecting thermal efficiency may include;

- 1 Appliance Efficiency: The thermal efficiency of the fuel is based on the appliance efficiency. Appliances Efficiencies above about 85% do genuinely exist, but are likely to be highly problematical unless fitted with automatic control devices, or powered flue draught and used only with very high quality, very dry, fuel. Appliances of high efficiency are likely to give increased fuel consumption or be at risk of smoke, tar, rapid parts failure and dangerous fume emission. On the other hand, an appliance efficiency of less than about 65% is likely to

be wasteful, except in circumstances where you need to give a lot of heat into the flue (SOLIFITEC, 2015).

2 Moisture Content and Volatile Matter of fuel: A damp and high volatile matter fuel can reduce its thermal efficiency. This is because more energy will be used to exhume the moisture and volatiles before the heat energy is released. Consequently this energy is not available for the reduction reactions. Therefore high moisture contents result in low heating values and high burning rate.

3 Ash Content of Fuel: High ash content in fuel leads to slagging or clinker formation in the reactor, caused by melting and agglomeration of ashes. If no special measures are taken, slagging can lead to excessive tar formation and/or complete blocking of the reactor. A worst case is the possibility of blocking air-channels which can lead to a risk of explosion. Slagging impedes fuel thermal efficiency. The slagging behaviour depends to a large extent on the ash melting temperature, which is influenced by the presence of trace elements giving rise to the formation of low melting point eutectic mixtures.

4 Turbulent or Intimate Mixing of Fuel and Oxygen: Too much or too little fuel with the available combustion air may potentially result in unburned fuel and carbon monoxide generation. A very specific amount of O₂ is needed for perfect combustion and some additional (excess) air is required for ensuring complete combustion. However too much air will result in heat and efficiency loss (Rathore, 2010).

5 Reactivity of Fuel: The reactivity is an important factor determining the rate of reduction of carbon dioxide to carbon monoxide. Reactivity depends in the first instance on the type of fuel. For example, it has been observed that fuels such as wood, charcoal and peat are far more reactive than coal. Undoubtedly, there is a relation between reactivity and the number of active places on the char surface, these being influenced by the morphological characteristics as well as the geological age of the fuel. The grain size and the porosity of the

char produced in the reduction zone influence the surface available for reduction and, therefore the rate of the reduction reactions.

6 Bulk Density of Fuel: Bulk density is defined as the weight per unit volume of loosely tipped fuel. Fuels with high bulk density are advantageous because they represent a high energy-for-volume value. Consequently these fuels need less bunker space for a given refueling time. Low bulk density fuels sometimes give rise to insufficient flow under gravity, resulting in low gas heating values and ultimately in burning of the char in the reduction zone.

7 Fuel Energy Content: The energy efficiency of the fuel to a great extent is dependent on its heating value. The heating /calorific value of fuel is the measurement of heat or energy produced and is measured either as Gross Calorific Value (GCV) or Net Calorific Value (NCV). Their difference is determined by Latent Heat of Condensation of water vapour produced during the combustion process. The calorific value of fuel varies considerably depending on the ash content, moisture content and the type of fuel (Shaka, 2013).

It is not normally practical to directly measure the heat output of a solid fuel. The thermal fuel efficiency is measured as a ratio of the net heat supplied to the water by the fuel over the net heat liberated by the fuel.

$$\text{TFE} = \frac{\text{Net heat supplied to the water}}{\text{Net heat liberated by the fuel}}$$

2.3.4 Proximate and Ultimate Analysis of Tannery Solid Waste

Tannery Solid Waste Analysis may be presented in the form of “proximate” and “ultimate” analyses, whose analytical conditions are prescribe by organisations such as the ASTM. A typical proximate analysis includes the moisture, ash, volatile matter, and fixed carbon contents. Table2.2 shows the characteristics of the waste at different stages in the tanning operation.

Table 2.2: The Average Value of Physicochemical Parameters of Tannery Solid Waste

Types of Tannery Solid wastes	pH	Moisture Content (%)	VOC (%)	Ash Content (%)	CV (kJ/kg)	C (%)	N (%)	C:N Ratio
Skins Trimmings	9.85	59.00	95.60	4.40	7853	53.11	34.71	1.53:1
Hair Waste	9.90	57.00	93.11	6.89	7888	51.73	44.63	1.16:1
Fleshings Pickle Trimmings	11.4	80.00	96.40	3.06	8998	53.86	13.10	4.11:1
Chrome Shaving Crust Trimmings	3.00	65.00	87.13	12.87	7694	48.41	15.24	3.18:1
Leather Trimmings	4.21	47.80	93.20	6.80	7663	51.78	63.10	0.82:1
	4.40	6.65	91.40	8.60	17,556	50.78	39.61	1.28:1
	4.80	9.83	97.30	2.70	18,772	54.06	48.7	1.11:1

Source: (Abajihad, 2012).

2.3.4.1 Moisture content of waste

Moisture content represents the amount of water present in a moist sample. It can be expressed on wet or dry basis. Moisture content on dry basis is the amount of water per unit mass of dry solids in the sample while on wet basis is the amount of water per unit mass of moist-or wet- sample (Berk, 2009).

2.3.4.2 Volatile matter of waste

Volatile matter refers to the components except for moisture, which are liberated at high temperature in the absence of air. This is usually a mixture of short and long chain hydrocarbons, aromatic hydrocarbons and some sulfur. The volatile matter is determined under rigidly controlled standards.

2.3.4.3 Ash content of waste

Ash content is the non-combustible residue left after TSW is burnt. It represents the bulk mineral matter after carbon, oxygen, sulfur and water has been driven off during

combustion. Analysis is fairly straightforward, with the waste thoroughly burnt and the ash material expressed as a percentage of the original weight.

2.3.4.4 Fixed carbon content of waste

The fixed carbon content is the carbon found in the material which is left after volatile materials are driven off. This differs from the ultimate carbon content because some carbon is lost in hydrocarbons with the volatiles. Fixed carbon is used as an estimate of the amount of coke that will be yielded from the waste sample. Table 2.3 shows the ultimate and proximate analysis of sub-bituminous coal by different authors. These parameters influences the heating value of the coal and are based on the factors mentioned earlier.

Table 2.3: Physico-Chemical Characteristics of Coal Briquettes

	ONUEGBU	HUTAGALUNG
Proximate Analysis		
Volatile matter	43.44%	27.50%
Ash content	18.27%	22.10%
Moisture content	7.64%	2.70%
Fixed carbon	30.64%	47.3%
Heating value	20 kJ/g	24.73 MJ/kg
Ultimate Analysis		
Carbon	53.07%	61.1%
Hydrogen	4.10%	3.0%
Oxygen	39.60%	8.8%
Sulfur	0.302%	0.4%
Nitrogen	0.28%	1.35%

Source: Onuegbu *et al.*, 2010 and Hutagalung, 2008.

2.4 SOLID WASTE MANAGEMENT

Solid waste management is the collection, transportation, storage, recycling or disposal of solid waste, or the subsequent use of a disposal site that is no longer operational. It is

a complex process because it involves many technologies and discipline. These include technologies associated with the generation (source reduction), on-site handling and storage, collection, transfer and transportation (densification), processing (waste -to- energy) by either; thermo-chemical technologies (incineration and pyrolysis/gasification) or biochemical conversion process (anaerobic/biomethanation), composting and disposal of solid wastes.

All of these processes have to be carried out within existing legal, social, and environmental guidelines that protect the public health and the environment and are aesthetically and economically acceptable. In ULF tannery following solid wastes are generated and managed as shown in Table 2.4

Table 2.4 Solid Waste generated in Unique Leather and how they are disposed

WASTE	UTILIZATION
Removed Salt From Cured/preserved Skin	Landfills, or disposed into effluent
Shavings	Landfills
Fleshings	Dissolved in hot water and drained into effluent
Bags from Chemicals	Landfills
Sludge from PTP	Landfills

Source: (UNIDO, 2004)

The objective of solid waste management is to reduce the quantity of solid waste disposed of on land by recovery of materials and energy from solid waste. Figure 2.1 below shows waste management hierarchy.



Figure 2.1: Waste Management Hierarchy

Source: (Abajihad, 2012).

In this research, densification technology was considered to manage tannery solid waste and proposed based on the Physico-chemical characteristics of the solid waste.

2.5 TANNERY DERIVED BRIQUETTES

The world's energy markets rely heavily on the fossil fuels; coal, crude oil, and natural gas as sources of thermal energy. Since millions of years are required to form fossil fuels in the earth, their reserves are finite and subject to depletion with consumption (Balat and Ayar, 2005). The only natural, renewable carbon resource known that is large enough to be used as a substitute for fossil fuels is biomass. Tannery solid waste has the potential to be used as feedstock for solid biomass fuel production through physical, chemical and biological conversion processes. Basically, the biomass has low energy, less density, bulking, occupy large volume of space and difficult in transportation. Conversion of biomass into fuel transforms the waste into a carbonaceous material, which may be a substitute for the conventional/fossil fuel. Plate 2.4 shows briquettes produce from rice husk. In fact the bio energy meets 14% of the total energy demand and the percentage will go up in the future. The biomass absorbs and emits carbon dioxide during growth combustion respectively and no contribution to the greenhouse effect.



Plate IV: Solid briquettes

Source: (BANZ, 2014)

Baling, briquetting, and pelleting are the most common biomass densification methods; pelleting and briquetting are the most common densifications used for solid fuel applications. Natural binders such as lignin, protein, and starches present in the feed stocks enhance the bonding between particles during densification process. Because of the application of high Pressures, particles are brought close together, causing inter-particle attraction forces, and the natural binding components in the feed stocks are squeezed out of the cells, which make solid bridges between the particles

2.5.1 BINDERS

Binders are natural occurring or artificially incorporated into the biomass for adhesion and cohesion of particles. Constituents such as lignin, protein, starch, fat, and water soluble carbohydrates are “natural binders” in the biomass materials. These natural binders can be activated (softened or melted locally) either by high moisture, elevated temperature or steam to use their binding functionality.

The binding functionality can be enabled (i.e., activated) by the auto-crosslinking reactions by lignin and fat; hydrogen bonding by highly polar components such as cellulose, lignin, starch, and protein; starch gelatinization; protein denaturation; solubilisation and subsequent crystallization of water soluble carbohydrates (Kaliyan *et al.*, 2010).

In general, natural binders such as lignin, protein, and starches present in the feed stocks

enhance the bonding between particles during densification process. Because of the application of high pressures, particles are brought close together, causing inter-particle attraction forces, and the natural binding components in the feedstocks are squeezed out of the cells, which make solid bridges between the particles (Karunanithy, 2012).

The cost of the binding material can be critical to the economic success of the project, so the smallest amount of binder necessary for an acceptable briquette should be used. Although a combustible binder is desirable, it is possible to use a non-combustible binder with good results. Alternative uses of the binder must be weighed against the value of the final product as an energy source. The following is a partial list of binding materials:

2.5.1.1 Types of Binder

Binders could be categorised as combustible and non-combustible binders

I. Combustible Binders

Combustible binders includes, natural or synthetic, resins, starch, tar, animal manure, sewage mud, fish waste, and algae.

II. Non-combustible Binders

This include slime, mud, clay and cement (Davies, 1985).

2.5.1.2 Starch

Starch is derived from crops having content of carbohydrate as such as tubers and cereals. It has been reported that compared to other binders, the briquettes made with starch as binder had higher calorific value, burning rate and heat output (Ugwu and Agbo, 2013). Starch is an organic substance called polysaccharide and its composition is mainly carbon, hydrogen and oxygen which do not alter the chemical composition of the tannery waste or make it toxic. Cassava starch has a moisture content of 13.09% on dry basis, ash content of 0.24%, a pH of 5.34 and a calorific value of 159.48 kJ/kg or 381 cal/110g (Chitedze *et al.*, 2012).

2.6 BIOMASS BRIQUETTING TECHNOLOGIES

The quality and strength of the compacted mass depends on the physical properties of the material, applied force and other process variables. The self-bonding of biomass to form a briquette involves the thermo-plastic flow of the biomass. The natural lignin content in biomass is liberated under high pressure and temperature. Lignin serves as the glue in the briquetting process that binds the particles of feedstock together which is then compressed into high density briquettes. It is also important to understand the compaction mechanisms in order to design energy-efficient compaction equipment and to quantify the effects of various process variables on density and durability (Edgars, 2011). Biomass densification represents a set of technologies for the conversion of biomass residues into a convenient fuel. The technology is also known as briquetting or agglomeration. Depending on the types of equipment used, it could be categorized into five main types:

2.6.1 Pelletizing Densification

Pelletizing is closely related to briquetting except that it uses smaller dies (approximately 30 mm) so that the smaller products are called pellets. The pelletizer has a number of dies arranged as holes bored on a thick steel disk or ring and the material is forced into the dies by means of two or three rollers. The two main types of pellet presses are: flat/disk and ring types. Other types of pelletizing machines include the Punch press and the Cog-Wheel pelletizer. Pelletizers produce cylindrical briquettes between 5mm and 30mm in diameter and of variable length. They have good mechanical strength and combustion characteristics. Pellets are suitable as a fuel for industrial applications where automatic feeding is required. Typically pelletizers can produce up to 1000 kg of pellets per hour but initially require high capital investment and have high energy input requirements (Maninder *et al.*, 2012).

2.6.2 Manual Presses and Low Pressure Briquetting

There are different types of manual presses used for briquetting biomass feed stocks. They are specifically designed for the purpose or adapted from existing implements used for other purposes. Manual clay brick making presses are a good example. They are used both for raw biomass feedstock or charcoal. The main advantages of low-pressure briquetting are low capital costs, low operating costs and low levels of skill required to operate the technology. Low-pressure techniques are particularly suitable for briquetting green plant waste such as coir or bagasse (sugar-cane residue). The wet material is shaped under low pressure in simple block presses or extrusion presses. The resulting briquette has a higher density than the original material but still requires drying before it can be used. The dried briquette has little mechanical strength and crumbles easily. The use of a binder is imperative (Maninder *et al.*, 2012).

2.6.3 Piston Press Densification

There are two types of piston press: 1 the die and punch technology and 2 hydraulic press. In the die and punch technology, which is also known as ram and die technology, biomass is punched into a die by a reciprocating ram with a very high pressure thereby compressing the mass to obtain a compacted product. The standard size of the briquette produced using this machine is 60 mm, diameter. The power required by a machine of capacity 700 kg/hr is 25 kW. The hydraulic press process consists of first compacting the biomass in the vertical direction and then again in the horizontal direction. The standard briquette weight is 5 kg and its dimensions are: 450 mm x 160 mm x 80 mm. The power required is 37 kW for 1800 kg/h of briquetting (Grover *et al.*, 1995). This technology can accept raw material with moisture content up to 22%. The process of oil hydraulics allows a speed of 7 cycles/minute (cpm) against 270 cpm for the die and punch process. The slowness of operation helps to reduce the wear rate of the parts. The ram moves

approximately 270 times per minute in this process.

2.6.4 Roller Press Densification

In a briquetting roller press, the feedstock falls in between two rollers, rotating in opposite directions and is compacted into pillow-shaped briquettes. Briquetting biomass usually requires a binder. This type of machine is used for briquetting carbonized biomass to produce charcoal briquettes.

2.6.5 Screw Press Densification

The compaction ratio of screw presses ranges from 2.5:1 to 6:1 or even more. Table 2.5 shows the specification for a biomass screw extruder. In this process, the biomass is extruded continuously by one or more screws through a taper die which is heated externally to reduce the friction (Koopmans, 1996). Here also, due to the application of high pressures, the temperature rises fluidizing the lignin present in the biomass which acts as a binder. The outer surface of the briquettes obtained through this process is carbonized and has a hole in the centre which promotes better combustion. Standard size of the briquette is 60 mm diameter.

Table 2.5: Specification for biomass screw extruder

Model	ZBJ-50
Dimensions, mm	2200×600×1400
Bar diameter, mm	45,50,55
Capacity, Kg/hour	150-180
Raw material humidity	8-12%
Power, KW	15
Electric heater, kw	3*1.5
Weight of machine, MT	11
Density of briquette, Ton	1.2-1.4

Overall dimension: 1700*800*1600mm

The out diameter of finished briquettes is 40-80mm.

Source: (Anon 1, 2014)

2.7 COMPARISON OF A SCREW EXTRUDER AND A PISTON PRESS

The briquettes produced by an extruder as shown in Plate 2.5(b), have a number of positive properties of which the key one is their high density. Their combustion is trouble free over a long period of time (about 180 – 240 minutes depending on the input raw materials used for their production). Extruded briquettes are usually of rectangular or hexagonal shape. One of a deficiency of the screw pressing method is its higher operating cost in comparison with mechanical and hydraulic piston presses. The reasons for this are:

- I. periodical need of stops to replace a screw;
- II. periodical need of manual control of several parameters such as clearance between the screw and die plate, temperatures of die plate heating, material moisture content;
- III. need for qualified personnel.

The production of fuel briquettes by the piston/hydraulic presses as shown in Plate 2.5(a), does not require such a high cost like the extruder technology (Alexandru *et al.*, 2012).

Table 2.6 gives an explicit difference between the two technologies.

Table 2.6: Comparison of Screw Extruder and Piston Press

	Piston Press	Screw extruder
Optimum Moisture Content of Raw Material	10-15%	8-9%
Wear of Contact Parts	Low in case of ram and die	High in case of screw
Output from the Machine	In strokes	Continuous
Power Consumption	50kWh/ton	60kWh/ton
Density of Briquette	1-1.2gm/cm ³	1-1.4gm/cm ³
Maintenance	High	Low
Combustion Performance of Briquette	Not so good	Very good
Carbonisation to Charcoal	Not possible	Makes good charcoal
Suitability in Gasifiers	Not suitable	Suitable
Homogeneity of Briquette	Non- homogeneous	Homogeneous

Source: Grovel *et al.*, 1996.



Plate V

(a) Hydraulic Press

Source: (Anon 2, 2015).



(b) Biomass Briquette Screw Extruder

Source: (Anon 1, 2014).

2.8 ADVANTAGES OF BRIQUETTE OVER RAW RESIDUE

Tannery solid waste can be combusted directly without being converted to briquette but there are some advantages associated with the conversion;

1. **Ease of handling and transportation:** the ease of handling and transportation extend through to the combustion device. This means that most residues can be combusted more efficiently when briquetted even in those cases where the plant can actually handle unprocessed residue.
2. **Combustion efficiency:** there is loss of combustion efficiency in burning raw residue. In India, it was claimed that raw rice-husk showed a 20% drop in efficiency as against rice-husk briquettes, though this was not based on rigorous measurements (Eriksson *et al.*, 1990).
3. **Source of renewable energy:** General experience suggests that briquettes are a good substitute for wood, possessing a consistent quality which can enable a price premium to be obtained over wood. The substitution of briquettes for coal depends on the Physio-chemical characteristics of the feedstock. For instance, rice-husk, has an unusually high ash content in this case, briquettes can be burnt satisfactorily only in a limited range of coal

appliances, for example step-furnaces. In other types, for example moving grates, the rice-husk briquettes can fall between grate bars before they are completely combusted. It is also possible that in some coal appliances there could be problems with ash-slagging but no data are known to exist about this.

4. Low smoke and CO₂ emission: The briquettes burn with somewhat higher flames and a less smoke than raw residue (Eriksson *et al.*, 1990).

2.9 DISADVANTAGES OF BIOMASS BRIQUETTING

Despite the merits of solid briquette as mentioned above there are some challenges in its production and applications;

1. High investment cost and energy consumption input to the process.
2. Undesirable combustion characteristics often observed e.g., poor ignitability, smoking, etc.
3. Tendency of briquettes to loosen when exposed to water or even high humidity weather.

2.10 FACTORS AFFECTING DENSIFICATION/ BRIQUETTING

The factors that greatly influence the densification process and determine briquette quality are:

2.10.1 Temperature and Pressure of Briquetting Machine

It was found that the compression strength of densified biomass depended on the temperature at which densification was carried out. Maximum strength was achieved at a temperature around 220°C. Densification of biomass under high pressure of about 150 MPa brings about mechanical interlocking and increased adhesion between the particles, forming intermolecular bonds in the contact area (Maninder *et al.*, 2012).

2.10.2 Moisture Content of Briquette

Moisture content has an important role to play as it facilitates heat transfer. Too high moisture causes; risk of self-ignition, fungi growth and spores emission (health hazard), poor and weak briquettes, and the briquetting operation gets erratic. Suitable moisture content could be of 8-12%. The moisture content has an effect on the calorific value (by mass) and energy content (by volume). It also determines the briquettes suitability for combustion particularly in domestic furnace.

2.10.3 Ash Content and Composition of Briquette

Biomass residues normally have much lower ash content (except for rice husk with 20% ash) but their ashes have a higher percentage of alkaline minerals, especially potash. These constituents have a tendency to devolatilise during combustion and condense on tubes, especially those of super heaters. These constituents also lower the sintering temperature of ash, leading to ash deposition on the boiler's exposed surfaces. The greater the ash content, the greater the slagging behaviour of biomass but this does not mean that biomass with lower ash content will not show any slagging behaviour. The temperature of operation, the mineral compositions of ash and their percentage combined determine the slagging behaviour. If conditions are favourable, then the degree of slagging will be greater. Minerals like SiO_2 , Na_2O and K_2O are more troublesome. Many authors have tried to determine the slagging temperature of ash but they have not been successful because of the complexity involved. Usually slagging takes place with biomass fuels containing more than 4% ash and non-slagging fuels with ash content less than 4%. According to the melting compositions, they can be termed as fuels with a severe or moderate degree of slagging (Grover *et al.*, 1996).

2.10.4 Drying

Drying depends on factors like initial moisture content, particle size, types of densifier, throughout the process. Drying can be done by naturally means in the sun or by force draft with a heater, or by using heated air recycled from the Gasifier.

2.10.5 Particle Size of Briquette

The finer the particle size, the easier the compaction process. Fine particles give a larger surface area for bonding. It is generally agreed that biomass material of 6-8 mm size with 10-20% powdery component (< 4 mesh) gives the best results. The particle size should be less than 25% of the densified product (Maninder *et al.*, 2012). This can be achieved by means of a hammer mill. Wood or straw may require chopping before further size reduction in the hammer mill. Although the screw extruder which employs high pressure (1,000 – 1,500 bar), is capable of briquetting material of oversized particles, the briquetting will not be smooth and clogging might take place at the entrance of the die resulting in jamming of the machine. That is why the processing conditions should be changed to suit the requirements of each particular biomass. Therefore, it is desirable to crush larger particles to get a random distribution of particle size so that an adequate amount of sufficiently small particles is present for embedding into the larger particles (Grover, 1995).

2.11 USES AND APPLICATIONS OF BRIQUETTE

Biomass briquettes are ready substitute of coal or wood in industries and homes for thermal application. They are non-conventional source of energy, renewable in nature, eco – friendly, non-polluting and economical. They also reduces deforestation caused by tree falling for firewood and charcoal. It has a variety of applications such as;

1. Industrial boilers and kilns
2. Forges and foundries

3. Household stoves and chimneys
4. Food processing industries
5. Gasifiers

2.12 ECONOMIC BENEFITS

The available source for biomass briquettes are municipal waste, industrial waste, sea weeds and agro residues. These are gotten as either by-products of industries or domestic waste. Their conversion to briquette will add economic value to the unwanted materials by;

- I. **Reducing disposal cost:** One of the popular option of tannery solid waste disposal is through landfills. Urbanization has become a challenge to this form of waste disposal. The areas used as landfills are constantly being reclaimed and structures are erected. As a result of this, the industry have to travel longer distances to dispose these waste. Production of briquette from the tannery solid waste will help reduce disposal costs.
- II. **Reducing energy cost:** Leather production in accordance with “best energy use practises” will require 30 kW of energy per hide. Approximately 85% of leather tannery energy requirements is accounted for by thermal processes such as drying, space heating and the heating of water. The remaining 15% of energy is utilized through electricity consumption (BLC, 2010). Briquette is a source of heat energy and electricity via gasification which could be used in the tannery to sustain the high energy requirement thus reducing energy costs.
- III. **Tax incentives:** Heat and electrical energy produced from briquette made from tannery solid waste will be tax free thereby reduce production cost.
- IV. **Long term solution:** the demand for alternative fuel sources is constantly increasing due

the incessant increase in price and rise in global warming caused by use of fossil fuel. Briquette produced from tannery solid waste is renewable, cheap and sustainable offering a long term solution to the waste generated.

V. Income from energy: the combine heat and power plant is highly desirable because it displaces non-renewable energy demand. This waste contains more than half of the energy value of coal. Depending on the waste stream and the blend of materials; sludge, and buffing dust will produce approximately 1 kw/h of energy per 1 kg of waste (Addy, 2004). This energy can be commercialise and used to operate small business.

2.13 FINANCIAL ANALYSIS

The financial costs of briquetting are dependent upon the nature of the project, in particular upon the raw materials used and the plant location. The objective of this section is to provide an indication of what range of costs can be expected for both operating and capital costs and what is the resulting unit product cost. Whether or not briquetting is economic in any given location will depend critically upon how these unit costs relate to the price of the likely substitute fuels. Such prices vary so widely that it is impossible to generalise about the likely economic benefits of briquetting. It is hoped that the costs set out will enable some preliminary decisions to be made as to the likely role of briquetting in particular circumstances.

2.13.1 Fixed Capital and Operating Capital

Fixed capital is the cost of the plant ready for start-up. It is the cost paid to the contractors (Sinnott, 2009). These include:

- 1 Design and other engineering and construction supervision
- 2 All items of equipment's and their installation

- 3 All piping, instrumentation and control systems
- 4 Building and structures
- 5 Auxiliary facilities, such as utilities, land and civil engineering work.

Working capital on the other hand is the extra investment needed, over and above the fixed capital to start the plant up and operate it to the point when income is earned. Most of the working capital is recovered at the end of the project. The total investment needed for a project is the sum of fixed and working capital. The working capital includes the cost of;

- 1 Start-up
- 2 Raw materials and intermediate in the process
- 3 Finished product inventories
- 4 Funds to cover outstanding accounts from customers.

2.13.2 Cost Estimation

There are a number of different ways of estimating cost of constructing a chemical plant. Some require very little information and some require a complete listing of every item from pipe fittings to storage tanks, electrical sockets, and generators. All assumed to be in a normal condition and having a normal schedule (Sinnott, 2009).

2.13.3 Cost Escalation

The cost of materials and labour are subject to inflation in a country like Nigeria. Cost data available are usually those pertaining to the past. The method usually employed to update historical cost data makes use of published cost indices. These cost indices relate the present costs to the past, and are based on data for labour, material and energy costs published in trade journals (Sinnott, 2009).

The Chemical Engineering plant cost index uses an average of 1957-1959, based on four components and weighed as follows:

- 1 Equipment's, machineries, and supports 61%
- 2 Erection and installation labour 22%
- 3 Building and supervision 7%.

2.13.4 Rapid Capital Cost Estimation Method

As a chemical plant increases in size, its cost also increases. However, there is not a linear relationship between capacity and cost. If the size doubles, the cost will not increase two-fold. There are many reasons why it is like that.

Firstly, equipment costs do not increase linearly with size, since the amount of metal used is more closely related to the area than the volume of the vessel.

Secondly, actual construction costs are not twice as much. For example, the wiring of a 10 hp pump does not take much longer than the wiring of a 5 hp pump. Also, for the fact that the costs of engineering, drawing, ordering, and so on do not increase much with size, for example, the calculation of the stresses on a reactor takes the same amount of time regardless of the size.

A typical curve which gives the cost of a particular plant versus capacity can be expressed in the equation form as (Perry, 1997).

$$C_2 = C_1 \left(\frac{Q_2}{Q_1} \right)^n \quad (2.1)$$

Where C_2 = cost in dollars of a plant of capacity A
 C_1 = cost in dollars of a plant of capacity B

n = cost index

The use of this equation together with the engineering indexes is the easiest of estimation plant costs.

2.13.5 Factorial Cost Estimate

For chemical process plants, capital cost estimates are based on estimates of the purchase cost of the major equipment items required for the process, the other costs being estimated as factors of the equipment cost.

These methods include the following steps:

- 1 Estimation of the purchase cost of major equipment items.
- 2 Calculation of the total physical plant cost (PPC) using the appropriate factors

$$PPC = PCE(1 + f_1 + f_2 + \dots + f_i) \quad (2.2)$$

PCE – Purchased Cost of Equipment

$$\text{Total fixed capital} = \text{Direct cost} + \text{Indirect costs} \quad (2.3)$$

Estimation of working capital as a percentage of the fixed capital (5 to 20%) Total

$$\text{investment} = \text{fixed capital} + \text{working capital}. \quad (2.4)$$

(Sinnott, 2009)

2.13.6 Cash Flow

Cash flow in any process industry can be likened to the material flows. The inputs are the cash needed to pay for research and developments; plant design and constructions, and plant operation. The outputs are goods for sale, and cash is recycled to the organization from the profit earned. The cash flows are based on best estimate of investment, operating cost, sales volumes.

2.13.7 Discounted Cash Flow (Time Value of Money)

Since one usually uses the money earned in any year to reinvest it as soon as possible to make profit, this means that the money earned in early years is more valuable than that earned in future.

The net cash flow in each year of the project is brought to its “present worth” at the start of the project by discounting it at some chosen compound interest rates.

$$\text{Net Present Value (NPV)} = \frac{\text{Estimated net cash in year } n}{(1+r)^n} \quad (2.5)$$

Where r = the discount rate percent

2.13.8 Rate of Return (ROR)

This is the ratio of annual profit investment, and is a simple index of the performance of the money invested. The simplest method of this calculation is to base the ROR on the average income over the life the project and original investment (Sinnott, 2004).

$$\text{ROR} = \frac{\text{cumulative net cash flow at the end of the profit}}{\text{life of project of original investment}} \times 100 \quad (2.6)$$

2.13.9 Payback Period

This is the period required after the start of the project to pay off the initial investment from income. It is often used to judge small improvement project on operating plant. Payback time is a criterion of investment performance.

$$\text{Pay-back Period} = \frac{\text{net investment}}{\text{profit after tax+depreciation}} \quad (2.7)$$

2.14 RELATED WORKS

Many researchers have worked on agricultural waste, weeds and their energy potentials: apple pomace (Jewell and Cummings, 1984), rice husk (Singh *et al.*, 1990), coffee waste (Antolin *et al.*, 1996), orange pomace (Enweremadu *et al.*, 2004), soybeans and cowpea (Enweremadu *et al.*, 2004), rice husk, bagasse and water hyacinth (Jindaporn *et al.*, 2007), rice husk, corn cob and waste paper (Daniel, 2008), water hyacinth and plantain peels (Davies, 2012). Tannery solid waste have been used as a sources of construction material, biogas, manure, adhesive and poultry feeds:

1. Md. Safiuddin *et al.*, in 2010, investigated the potential use of various solid wastes such as

agro-waste (bagasse), industrial waste (coal combustion residue), non-hazardous waste (waste gypsum) and hazardous waste (tannery waste) for producing construction materials. From the investigation, a tremendous scope for setting up secondary industries for recycling and using such huge quantity of solid wastes whose current storage/disposal poses serious environmental treat, as minerals or resources in the production of construction materials which are environment-friendly, energy-efficient, and cost-effective where realized

2. Sandeep *et al.*, in 2010, investigated the conversion of tannery waste by anaerobic digestion or gasification technology to an energy source for the tannery's own requirements, combine heat and power (CHP) or electricity export from the site for commercial purpose. These author concluded that introducing a waste-to-energy plant in a tannery will promote the production of electricity from decentralized renewable energy sources as well as resolve serious environmental issues posed by leather industry waste.

3. Onyuka from Northampton University in 2010, carried out a research on sustainable management of tannery hair waste through compositing. He used thermal and chemical pretreatment (potassium thioglycolate and sodium hydroxide) to enhance susceptibility of white, black and brown bovine hair to enzymatic and microbial degradation. He concluded that although chemical pretreatment was more effective, it was considered non-compatible with the compositing process and consequently, combined enzymatic and microbial degradation were more suitable alternative compared to using individual enzymes. Comparative solubilisation of white, black and brown hair showed that the percentage of nitrogen was more in white hair and least in brown hair.

4. In 2012, Hanna *et al.*, in their thesis title "Determination of Optimum Condition for The Production of Commercially Viable Glue from Tannery Solid Waste", investigated parameters such as type of reagents used (lime and sulphuric acid), concentration of reagents,

boiling time, soaking time and boiling temperature in the production of glue from animal skin, hide trimmings and fleshing. It was discovered that even though sulphuric acid produced a greater quantity of glue within a shorter, the quality of glue produced by soaking in lime at a longer period and lower temperature was better and commercially viable.

5. Paul *et al.*, in 2013 presented a paper titled “Towards Zero Solid Waste: Utilising Tannery Waste as a Source Poultry Feed”. The potential of tannery solid waste as a poultry feed additive was investigated. The team used oxidation method to achieve 95% de-chroming rate from the waste and then carried out thermal and enzymatic treatment to produce gelatin solution and collagen concentrate. The concentration of protein and fourteen amino acids were determined using High Performance Chromatography. The results were compared with wheat and soya beans meal conventionally used in poultry feeds. It was concluded that the concentration of arginine, leucine, threonine, serine and methionine were present in sufficient levels for use as additive in poultry feed production.

CHAPTER THREE

3.0 MATERIALS AND METHODOLOGY

3.1 EQUIPMENT

Table 3.1 contains the equipment that were employed in the development and characterization of tannery derived briquette (TDB).

Table 3.1 Equipment used in production and analysis of TDB

S/N	NAME	MODEL	AVAILABILITY
1	Thomas-Willey Lab. Mill	4	NILEST
2	Wenzhou Zhiguang Compression Molding Machine	ZG-ZXZSD2	NILEST
3	Ohaus Chemical Weighing Balance	AR1530	NILEST
4	Gallenkamp Oven	OV-010 (9A-122-B)	NILEST
	Nabertherm Furnace (30-30000C)	LH120/14	ChED, ABU
6	Parr Oxygen Bomb Calorimeter	A1329DD	ChED, ABU
7	Phenom ProX Scanning Electron Microscope	800-07334 (MVE016477830)	ChED, ABU
8	ELE Compressive Strength Testing Machine,	1223 (3)	Building Dept, ABU
9	Miniature Neutron Source Reactor (MNSR)	NIRR-1	CERT, ABU
10	ORTEC High Purity Germanium Detector (HPGe),	GLP-16195	CERT, ABU
11	Briquette mold		AgED, ABU
12	Biomass Stove		Samaru market

3.2 MATERIALS

The materials that were used in the production of the briquette are listed in Table 3.2.

Table 3.2: List of materials used in the development of briquette from tannery solid waste.

Materials	<ul style="list-style-type: none">• Tannery solid waste from UFL, Kano• Cassava starch• Aluminum foil• Distilled water• Silicon oil
------------------	---

3.3 METHODOLOGY

3.4 SAMPLE COLLECTION

Solid waste samples from pre-fleshing, lime fleshing, shaving, buffing and trimming, randomly selected among piles from the various leather operation units in Unique Leather Finishing Company in Sharada-Phase II, Kano, were examined within the scope of this study. In all, 600 kg of the waste were collected for the study.

3.5 SAMPLE PRE-TREATMENT

Pre-treatment involved sorting, drying, size reduction, calcination and maceration.

3.5.1 Sorting

The feedstock were sorted manually to remove impurities such as pieces of wood, bone, metal and any other unwanted material

3.5.2 Drying

Hair, Pre-fleshing and lime fleshing wastes from the beam house/pre tanning unit were air dried to reduce the moisture content (up to 90% dryness) and then they were evenly mixed and oven dried at 50°C. Chrome shavings and buffing dust from tanned leather wastes were oven dried at 105°C (Ozgunay *et al.*, 2007). The local starch used as binder was air dried at room temperature for 48hrs.

3.5.3 Size Reduction

The biomass were then reduced in size by milling until it could pass through a screen or

reaches a suitably small and uniform size (1mm). The hair waste being very light was reduced to 0.5mm.

3.5.4 Calcination

500g of each of the dried samples were put in a crucible and placed in an oven at a temperature of 450°C for 30min. The calcined samples were then transferred into a silver plate to reduce the temperature and avoid further combustion. Plate 3.1 shows solid waste material after calcination.



Plate VI: calcined hair (HR), fleshing (FL), chrome shavings CS)

and buffing Dust (BD) from right to left.

3.5.5 Maceration

The waste was macerated to provide uniform consistency (slurry). Maceration of the carbonised HR, FL, CS and BD samples was done by mixing equal amount of each sample with cassava starch binder and water at the ratio of 4:5:1 (Wessapan, 2010) while the non-carbonised feed were macerated by mixed varying amount of each sample with the binder and water at the same ratio. The starch was mixed with hot water to form a slurry before adding the feeds so as to facilitate flow of lignin present in the biomass which acts as a natural binder to increase adhesion between intermolecular particles. Total volume of water used was 120cm³.

3.6 PRELIMINARY TEST

3.6.1 Neutron Activation Analysis (NAA)

The Nigerian Research Reactor 1 (NIRR-1) was used to determine the concentration of elements in each of the raw sample. The samples were not pretreated to avoid destruction of the compositing materials but the particle size must not be above 1mm for solid substances. The analysis was neutron base forming radioactive isotopes. The radioactive active decay path of each element (already known) was used to study the spectra of the radioactive samples. Plate 3.2 shows the NIRR-1. Counting of induced gamma rays in the activated products was carried out using PC-based gamma-ray spectrometry set up which consists of a horizontal dip-stick High-Purity Germanium (HPGe) detector as shown in Plate 3.2 (b). As different isotopes have different half-lives, counting was delayed for 3 weeks to allow interfering species to decay. This technique provides multi-element analysis with minimum detection limits in sub-ppm range.

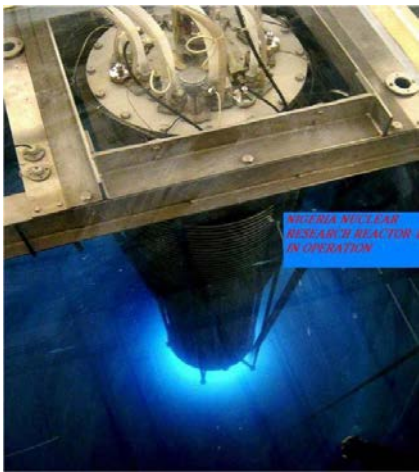


Plate VII: (a) NIRR-1



(b) Gamma Ray Spectrometer based
on High Purity Germanium
Detector

3.6.2 Scanning Electron Microscopy (SEM) Analysis

SEM analysis was carried out at Chemical Engineering Department, ABU with Phenom ProX Scanning Electron Microscopy to determine the morphology of the particles present in the biomass feed before and after calcination and also their elemental composition. The equipment was setup and connected to an electrical power source according to specification. The sample were dried up to 90% moisture removal which could form vapour while in the vacuum. The sample was reduced to a particle size of at 1mm. it was later coated with platinum to make it conductive. 2 g of each specimen was stably mounted on the stage of the microscope. The electron gun at the top illuminated the specimen and formed a source of electron beam which were accelerated towards the anode, held at earth potential relative to 15kV. The electron beam struck the specimen causing the emission of photon and electron signals. The beam angle was controlled by the condensers lens. The lens placed below the specimen was used in magnifying the image. The raster was adjusted to a magnification of 10,000. The Energy Dispersive X-ray Spectrometer was used to analyse characteristic X-ray spectra by measuring their energies. The X-ray forms a wide range of elements analysed simultaneously. Acquisition of an image from the detailed secondary electrons was displayed on the monitor after successive reductions in diameter by few tenths of nanometer at some points on the specimen surface along the path of the electron beam.

3.7 BRIQUETTING

Biomass briquette mould with a capacity of 150g per die consisting of eight die arranged in two rows was fabricated from and used for briquetting. Each die was 40mm by 120mm dimension. The lib of the mould had eight metallic suspensions arranged to fit into each die during compression as shown in Plate 3.3 (a). Each of these suspensions were protruded by 35mm by 20mm dimension to freely fit into the cylinders. The die was

lined with aluminium foil and lubricate silicon oil to prevent friction while producing the briquette. Six different formulations as shown in Table 4.3 were used to produce six briquette samples by pressing the mould in a compression moulding machine at a pressure of 38.61k Pa and at a temperature of 150°C for 2hrs as shown in Plate 3.3 (b). The resultant was a condensed briquette of 40*80mm as shown in Plate 3.3 (c). The briquette was allowed to cool and dry for 2 weeks before carrying out proximate, mechanical and energy evaluation analysis.



Plate VIII: (a) Fabricated Briquette mould



(b) ZG-Compression Mould Machine



(c) Briquettes from Tannery Solid Waste

3.8 CHARACTERIZATION OF BRIQUETTE

Characterization depends on the physical properties and chemical properties of the raw material. In this context, the Charcoal briquettes will be taken as base/standard. Table 3.3 represents some of the standards that were adopted in the characterization of the raw materials and briquettes produced.

Table 3.3: Quality Characteristic in Standardisation

Combustion Related Properties	Standard Method
Moisture Content	CEN/TS 14774
Calorific Value	CEN/TS 14918
Volatile Matter	CEN/TS 15148
Ash Content	CEN/TS 14775
Mechanical Properties	
Bulk Density	CEN/TS 15103
Durability Compression	CEN/TS 15210
Compression Strength	CEN/TS 3114

Source: Han *et al.*, 2012

3.8.1 Calorific Value

The calorific value was determined by using Parr Oxygen bomb calorimeter in accordance with CEN/TS 14918 Standard Method. 2g of each sample were weighed into crucibles. The crucible was placed in the support pillar on the base of the bomb. A piece of platinum firing wire was stretched across the inner terminal with a piece of cotton thread 50mm long attached to it on one end. The other end was dipped into the centre of the sample in the crucible. The bomb was placed in its position on top of the crucible. A thermocouple attached to the bomb, was plugged into the socket. The bomb was then charged with oxygen to a pressure of 25 atm.

and ignited by momentarily closing the fire circuit. The reading on the galvanometre was recorded and the calorific value of samples were calculated by the equation;

$$Q_v = \frac{C(Q_1 - Q_2)}{W_b} \quad (3.1)$$

Q_v = Heating/Calorific Value (kJ/kg)

C = Calibration of constant for biomass acid (0.6188)

Q_1 = Galvanometre deflection without sample

Q_2 = Galvanometre deflection due to test sample

W_b = Weight of sample

3.8.2 Durability

The durability of the briquettes were determined using a pellet durability tester CEN/TS 15210. About 500 g of briquettes was divided into two batches of 250 g each. Each batch was placed in the pellet durability tester for a period of 10 min and operated at 50 rpm. The sample was then placed on a no. 4 sieve (4.75mm) before and after tumbling and measured for the mass retained on the screen. The pellet durability was then calculated using the following equation.

$$Durability = \left(\frac{Mat}{Mbt} \right) \quad (3.2)$$

Where Mat is the mass of the briquettes retained on the screen after tumbling (g), and Mbt is the mass of the briquettes retained on the screen before tumbling (g).

3.8.3 Density

Bulk densities of ground feed stocks and briquettes were measured following the Standard Method CEN/TS 15103. The container used was a 5-50L container. The bulk density was calculated from the mass of feed stocks and briquettes that occupied the container.

$$Density = \frac{m}{V} \quad (3.3)$$

Where m is the weight of the sample, V is volume of the vessel.

3.8.4 Determination of Compressive Strength

Mixtures were removed from the standard cylindrical forms in the mould and air dried for 2 days. The resulting solids were crushed to determine compressive strengths according to (CEN/TS 3114) standard in the Laboratory of Structural Materials, Department Building, ABU, Zaria. This experiment was carried out in the 'A' scale of the compressive strength testing machine.

3.8.5 Proximate Analysis

3.8.5.1 Percentage volatile matter

The percentage volatile matter (PVM) were determined by pulverising 2 g of the briquette sample in a crucible and placing it in an oven until a constant weight is obtained. The briquettes was then be kept in a furnace at a temperature of 550°C for 10 min and weighed after cooling in a desiccator (Standard Method CEN/TS 15148).

The PVM was calculated using;

$$\text{PVM} = \frac{A-B}{A} * 100 \quad (3.4)$$

Where; A is the weight of the oven-dried sample and B is the weight of the sample after 10 min in the furnace at 550°C.

3.8.5.2 Percentage moisture content on dry basis

The percentage moisture content (PMC) were obtained by weighing 3g of the briquette sample (E) and oven drying it at $105 \pm 2^\circ\text{C}$ until the mass of the sample was constant. The change in weight (D) after 16-24hrs was then use to determine the sample's PMC using;

$$\text{PMCdb} = D/E*100 \quad (3.5)$$

(Standard Method CEN/TS 14774).

3.8.5.3 Percentage ash content

The percentage ash content (PAC) were determined by heating 2 g of the briquette sample in the furnace at a temperature of 450°C for 60min and weighed after cooling in a desiccator to obtain the weight of ash (C). The PAC was determined using;

$$\text{PAC} = \frac{C}{A} * 100 \quad (3.6)$$

(Standard Method CEN/TS 14775).4ez

3.8.5.4 Percentage fixed carbon

The percentage fixed carbon (PFC) were computed by subtracting the sum of PVM, PAC and PMC from 100 as shown below

$$\text{Fixed Carbon} = 100\% - (\text{PVM} + \text{PAC} + \text{PMC}) \quad (3.7)$$

3.8.6 Ultimate Analysis

Estimations of important chemical elements that make up biomass, namely carbon, hydrogen, oxygen, nitrogen and sulfur, was determined through ‘ultimate’ analysis. These properties were obtained using Scanning Electronic Microscope (SEM) From Chemical Engineering Department, ABU, Zaria and Neutron Activation Analysis (INAA) from Centre of Energy Research and Training (CERT), ABU, Zaria.

3.9 ENERGY EVALUATION ANALYSIS

3.9.1 Thermal Fuel Efficiency (TFE) Test

100 litres of water was measure and pour into a pot. The pot contain the water was kept on a biomass stove and covered with proper lid to minimize loses by evaporation. A thermometer was fixed in the central part of the pot as shown in Plate 3.4. 1.5kg of the briquettes was measured and made into 4 parts for testing. The ambient temperature T_a of water in the pot was taken. The setting time of fire was recorded after lighting the fire. The final temperature of water T_b after boiling was measured. The water was heated until evaporation and briquette completely exhausted. The lid was removed and evaporation continued for

20 min. the pot was removed from the stove and allowed to cool for 2hrs. The final volume of water was measured. The time between T_o and T_b was measured using a stop watch (Rathore, 2008 and Onuegbu *et al.*, 2011). The thermal fuel efficiency was worked out as follows;

$$\text{TFE} = \frac{M_w C_p (T_b - T_o) + M_e L}{M_f E_f} \times 100\% \quad (3.8)$$

M_w = mass of water (kg)

C_p = specific heat of water (kJ/kgK)

T_b = boiling temperature of water (K)

T_o = initial temperature of water (K)

M_e = mass of water evaporated (kg)

L = latent heat of evaporation (kcal/kg)

M_f = mass of fuel burnt (kg)

E_f = calorific value of fuel kJ/kg)



Plate IX: Thermal Fuel Efficiency Analysis

3.9.2 Burning Rate

The burning rate is the rate at which certain mass of fuel is combusted in air. It were determine according to Ndirika (2002). An insulated wire guase of known weight was

used. 100 g of the briquette was placed on the wire gauze and the burner ignited. At every 10 sec. using a stop watch, the weight of the gauze was determined until briquette was completely exhausted and a constant weight retained. The weight loss at specific time was computed using the formular below;

$$B_s = \frac{Q_1 - Q_2}{T} \quad (3.9)$$

B_s = burning rate (g/min)

Q_1 = initial weight of fuel prior to burning (g)

Q_2 = final weight of fuel after burning (g)

T = total burning time (min)

3.9.3 Ignition Time

This is the time taken for a known mass of fuel to ignite. 100 g of briquette was placed on a wire mess grid (of known mass resting) in between two fire retard bricks to allow free flow of air around it. A Bunsen burner was placed directly underneath this platform and adjusted to a blue flame. Burner was lighted until the briquette was ignited (Onuegbu *et al.*, 2011). The ignition time was computed using the formular below;

$$\text{Ignition Time} = t_1 - t_0 \quad (3.10)$$

t_1 = time the briquette ignited (min)

t_0 = time the burner was lighted (min)

3.10 ECONOMIC ANALYSIS

This research has been concerned with the utilisation of solid waste generated from Unique Leather, Sharada-phase 1, Kano state as renewable energy in the form of briquette. This briquette generated is intended to serve as a substitute to coal which is a fossil fuel. As a result of the growing worldwide concern regarding environmental impacts - particularly

climate change - from the use of fossil fuels, the volatile fossil fuel market and the need for an independent energy supply to sustain economic development, there is currently a great interest in renewable energy in general and biomass energy in particular. The tannery derived briquette will serve as a feedstock for to generate electricity, heat, combined heat and power, and other forms of bioenergy.

The technology employed in the production process is not complex. However, in the final analysis, the proposed design can only be acceptable if the process is profitable. Hence an estimate of the investment required and the cost of production is required before the profitability of the project can be assessed.

Basis:

Two machines each 720 kg/hr

Production capacity = 1.44 T/hr (20 hrs/day operation)

Operating days per year	300
Operating hours per year	6,000
Capacity utilization	85%
Raw material	8,000 (TPY)
Moisture losses	350 (TPY)
Briquettes produced	8,460 (TPY)
Briquettes consumed (Dryer)	600 (TPY)
Saleable production	7,860 (TPY)

3.10.1 Cost of Equipment

In this section, the costs of equipment in the process plant are estimated using the appropriate calculation methods and the results are shown below;

Table 3.4: Cost of Equipment

Equipment	Cost (₦)
Oven	198,900
Mill	79,560
Screw Press	716,040
Mixer	318,240
Total	1,312,740

Source: (Anon 3, 2014).

3.10.2 Fixed Capital Evaluation

From Table 3.4, the total equipment cost is given as

Purchase Cost of Equipment (PCE) = ₦ 1,312,740

Physical Plant Cost (PPC) = PCE (1+f₁+...+f₆) (3.11)

Fixed Capital = PPC (1+f₇) (3.12)

3.10.3 Working Capital

Working capital is taken as 5% of fixed capital

3.10.4 Total Investment

Total investment required is the sum of the fixed and working capital

3.10.5 Variable Cost

The variable operating cost of the plant include;

- 1 Raw material cost
- 2 Labour
- 3 Electricity
- 4 Water Analyst cost

3.10.6 Annual Production Cost

The annual production cost of the plant is given by the following equation

$$\text{Annual production cost} = \text{Variable cost} + \text{Fixed cost} \quad (3.13)$$

3.10.7 Production Cost per kg

$$\text{Production Cost/kg} = \frac{\text{Annual production cost}}{\text{Annual production rate}} \quad (3.14)$$

(Sinnott, 2009)

3.10.8 Annual Profit

Revenue is generated only from the desired product (tannery derived briquette) but since other by-products like composite manure can be derived pre-treatment unit, this could also add up to the total sales. In line with that, the following economic evaluation was carried out.

$$\text{Annual profit} = \text{Annual sales} - \text{production cost} \quad (3.15)$$

3.10.9 Pay-Back Period

$$\text{Pay-back period} = \frac{\text{Net Investment}}{\text{Profit after tax} + \text{Depreciation}} \quad (3.16)$$

5% was taken to be the tax rate as required for a new process plant design (GISTAREA, 2013).

3.10.10 Return on Investment (ROI)

The simplest way of calculating return on investment is by taking the inverse of pay-back time.

$$\text{ROI} = \frac{1}{\text{pay back period}} \times 100\% \text{ or} \quad (3.178a)$$

$$\text{ROI} = \frac{\text{Profit before tax}}{\text{Net investment}} \times 100\% \quad (3.178b)$$

3.11 COMPARATIVE ANALYSIS FOR DIFFERENT FUELS

A basis of 1 litre of water was used. The water was heated using the briquette produced until it boils. The quantity of briquette calculated as the sum of individual known mass added until the water boils. The same procedure was repeated for coal and firewood. For the kerosene fuel, a known volume was measured (V_0) and put in the stove before heating began and the remaining volume (V_1) was also measured after the water had boil. The difference in volume was recorded as the amount of kerosene fuel used. The obtained value was converted to weight by multiplying with its density. The relative heat intensity, relative length of burning and amount of smoke produced were determine based on physical investigation.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 NEUTRON ACTIVATION ANALYSIS

Neutron Activation Analysis result of the elemental analysis of raw samples (hair-HR, fleshing-FL, chrome shavings-CS and buffing dust-BD) is shown in Table 4.1. It represents the precise and accurate elemental composition of each raw sample. All results are in milligram per kilogram (mg/kg).

Magnesium was only found in FL this is probably due to the presence of $Mg(HCO_3)_2$ suspected to be present in the water used in the process of soaking. Soaking is done to recover the dry hides and skin to its earlier state before preservation. It prepares the hide and skin for the process of unhairing and fleshing.

Chlorine was high in HR due to the presence of NaCl or brine used in curing (a method of preservation by salting). The bulk is retained in FL because of its absorption capacity. NH_4Cl used in deliming before chrome tanning to make the pelt susceptible to the tanning agent maybe responsible for the high Cl content in CS.

High amount of calcium was observed in the waste. Hides and skin have collagen substances rich in protein. Calcium in body fluids exists in two distinguishable forms, diffusible and non-diffusible. Non-diffusible calcium is bound to protein whereas the diffusible fraction is present largely as phosphate and bicarbonate compounds. Ca was highest in FL due to the presence of CaO and $Ca(OH)_2$ used in unhairing before fleshing. The high amount of sodium observed in the waste is due to NaOH, Na_2S or NaHS used in unhairing. It increases in CS due to the presence of Na_2CO_3 used for bacteria growth retardation.

Chromium(III)oxide salt (Cr^{3+}) used for tanning is suspected to be responsible for the high concentration of Cr in CS and BD. The total chromium value, greater than 3g/kg and below 5%, render these waste non inert and non-hazardous according to Portuguese law.

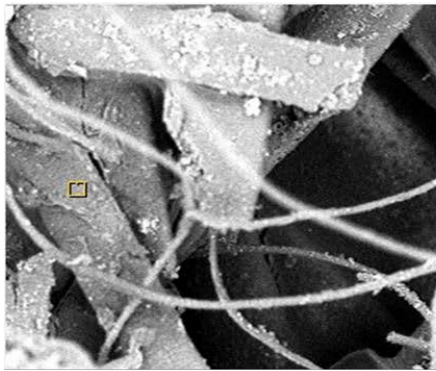
Table 4.1: Elemental Analysis of Raw Samples

ELEMENT	HR	FL	CS	BD
Mg	BDL	6770±528	BDL	BDL
Al	122±9	15190±198	2129±134	9612±87
Cl	2007±32	4118±58	68580±274	1612±34
Ca	3055±238	372300±3351	31440±1321	650±126
V	BDL	13.4±1.3	60.6±3.4	8.7±0.7
Mn	4.7±0.1	157±1	NA	5.8±0.1
Na	2413±10	5820±12	6562±7	3054±9
Sr	BDL	383±21	NA	BDL
K	663±114	1259±180	BDL	BDL
La	BDL	1.5±0.1	BDL	7.1±0.2
Sm	BDL	0.16±0.02	0.22±0.05	0.94±0.04
Sc	0.09±0.01	0.51±0.02	0.43±0.02	1.15±0.02
Cr	19.9±0.3	46.7±0.5	4909±5	4441±4
Fe	387±40	4153±75	903±57	836±50
Co	BDL	0.23±0.02	0.08±0.02	0.16±0.02
Zn	82±5	187±6	33±4	29±3
Br	1.8±0.2	1.1±0.2	9.4±0.3	0.9±0.1
Rb	6±2	6.5±1.5	BDL	4.7±1.4
Sb	BDL	BDL	0.031±0.005	BDL
Ba	BDL	56±13	BDL	BDL
Eu	BDL	BDL	BDL	0.21±0.04
Yb	BDL	0.34±0.06	BDL	BDL
Th	BDL	0.12±0.01	0.21±0.04	0.16±0.03

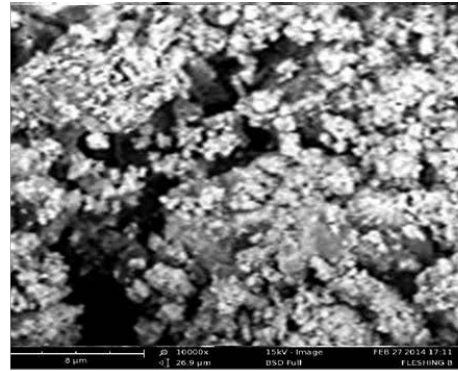
HR- hair, **FL-** fleshing, **CS-** chrome shavings and **BD-** buffing dust.

4.2 SCANNING ELECTRON MICROSCOPIC (SEM)

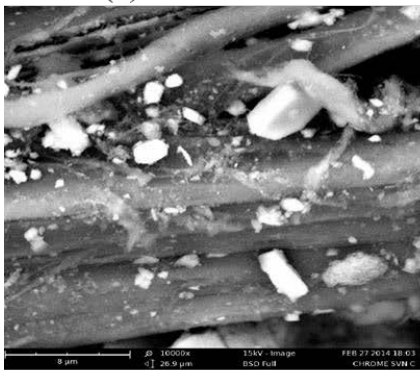
The SEM result of raw samples is shown in Plate 4.1 reveals the fine collagen fibre network of the processed skin. The fibre of HR is vertically arranged while that of CS is horizontally arranged and more tightly packed than BD due to the pre-tanning operations. FL has shorter strands since it is more of adipose fats. The particle sizes ranges from $1.64 \mu\text{m}$ to $39.73 \mu\text{m}$ in diameter and the results were observed at $1.50 \mu\text{m}^2$ to $8,797.58 \mu\text{m}^2$ pore areas within flash point/area.



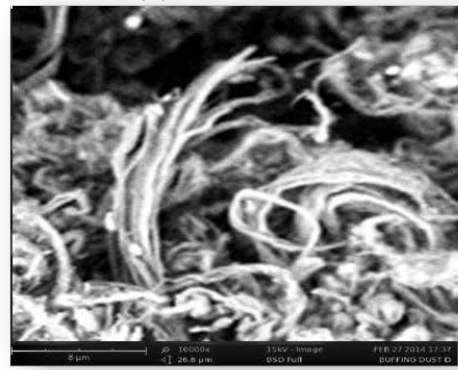
(a) HR



(b) FL



(c) CS

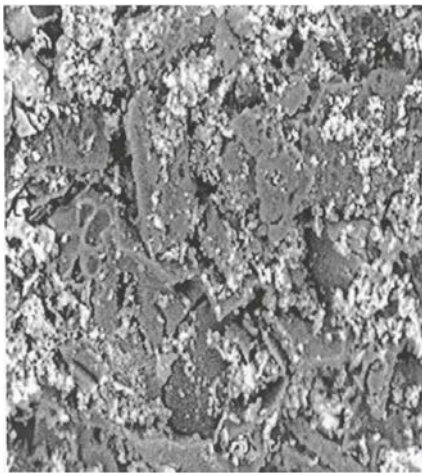


(e) BD

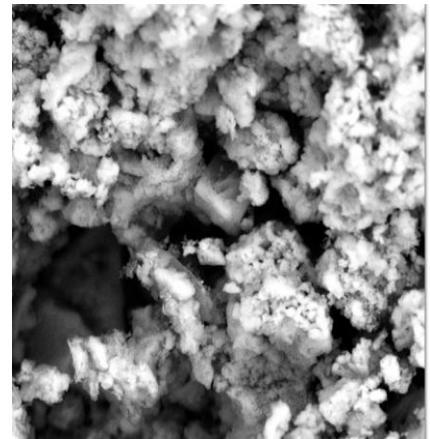
Plate X: SEM Analysis Result of Raw Samples at 15 kV X 10,000 Magnification

The size and surface morphology of the carbonised residue obtained after pyrolysis of the raw sample was analysed through SEM. Plate 4.2 shows how the fine collagen fibre network has been distorted after pyrolysis. The surface area of chrome shavings and buffing

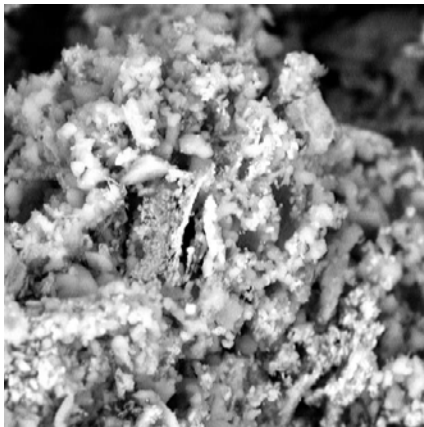
dust were finer than fleshing while the hair was coarser than others. The finer the particle size, the easier the compaction process during densification. Fine particles give a larger surface area for bonding. According to literature, the particle size should be less than 25% of the densified product. The particle sizes ranges from 277.30nm to 2.64 μm in diameter and results were gotten from 6433.98 nm^2 to 19.92 nm^2 pore areas within flash point/area.



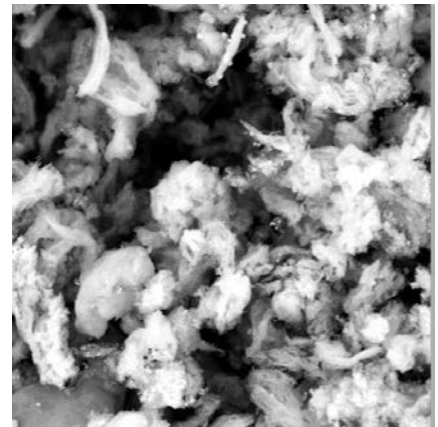
(e) Carbonised HR



(f) Carbonised FL



(g) Carbonised CS



(h) Carbonised BD

Plate XI: SEM Analysis Result of Carbonised Raw Samples at 15kV X 8,000 Magnification

4.3 pH OF RAW SAMPLES

The pH of HR and FL is basic as shown in Table 4.2 being 9.57 and 11.6 respectively. This is due to the presence of salt and lime used for preservation. The pH of HR is lower than that of FL because some of the salts in the process of handling have been lost as salt dust. In most cases, the salt is applied on the flesh side except in brimming where the entire hide/skin is submerged in the solution. HR and FL are waste from pretanning operations and before tanning, the pelt is made acidic by adding hydrochloric acid, ethanoic acid, or ammonium chloride. This process is called deliming and is responsible for the pH of CS being 4.13. After tanning and ageing, the wet blue is neutralized to a pH 6.5-10 before finally processing it into leather. This accounts for the pH of BD from the buffed finished leather being 5.37.

Table 4.2: Physico-Chemical Analysis of Raw Samples

SAMPLES	pH	MC (wt%)	VM (wt%)	AC (wt%)	FC (wt%)	CV (kJ/kg)
HR	9.57	4.982	9.699	2.78	82.54	9080.5
FL	11.6	6.750	14.500	3.45	75.96	14570.0
CS	4.13	5.900	10.087	2.53	81.48	10690.5
BD	5.37	1.023	9.405	2.35	87.22	11780.2

4.4 MOISTURE CONTENT

BD has the lowest moisture content of 1.0% as shown in Table 4.2. This is expected as it is from the finished leather which has undergone series of conditioning to make it impermeable to moisture indicating a good leather quality. The next lowest in moisture content is HR having a moisture content of 4.982% obviously due to its fibrous and polymeric nature. FL was observed to have the highest moisture content of 6.75%. This may be due to the presence of excess fat and collagen substances. The moisture content of samples 4 and 5 having high content of FL were also observed to be high present at

1.0892% and 1.2683% respectively as shown in Table 4.4. Moisture content facilitates starch gelatinization, protein denaturation and fibre solubilisation during briquetting (Grover and Mishra, 1996). Feed with high moisture content reduces the binding strength of the fuel as well as the density. The tolerance level of moisture content for briquette is between 8-12% depending on the nature of the feed (Chin and Siddiqui, 2000). Moisture content of briquette above tolerance level lowers its thermal efficiency as well as its burning rate. Consequently, more energy will be used to exhume the moisture. In a furnace a damp fuel will lead excessive emission of fumes and risk of explosion. Briquettes with high moisture content favours the growth of fungi and other micros.

Table 4.3: Formulations for Briquette Moulding

SAMPLES	HR(g)	FL(g)	CS(g)	BD(g)	ST(g)
1	10	10	10	10	60
2	15	10	5	10	60
3	5	15	15	5	60
4	15	25	5	5	50
5	20	50	15	15	0
6	10	10	10	10	60

Six briquettes were produced for analysis using the formulations as shown in Table 4.3. The characteristics and fuel properties of the briquettes vary greatly based on the composition of the waste and binder.

Table 4.4: Proximate Analysis of Briquettes

SAMPLE	MC (wt%)	VM (wt%)	AC (wt%)	FC (wt%)	CV (kJ/kg)
1	0.6844	2.1695	3.0555	94.09	20140.2
2	0.5317	2.2716	3.1402	92.38	19821.4
3	0.9521	2.7610	3.9031	93.23	18632.1
4	1.0767	1.8438	2.9349	94.13	22141.3
5	1.2615	2.1411	3.3714	93.22	24101.3
6	0.3807	1.8978	3.1105	94.61	21461.8

4.5 VOLATILE MATTER

The sample with the least volatile matter is expected to have the highest energy value. Samples 4 and 5 have in their composition greater quantities of HR and FL which from Table 4.2 are observed to have volatile matter of 9.7% and 9.4% respectively. This accounts for the low volatile matter observed in their briquette analysis as 1.8438% and 2.1411% as seen in Table 4.4. Sample 3 has the highest volatile matter of 2.7610% this implies that more energy will be required to burn off the volatile matter before the release of heat energy.

4.6 ASH CONTENT

Knowledge of the ash content tells the extent of clogging up of the burning medium. High ash content decreases the burning rate and reduces the heating value of fuel. Sample 4, as seen in Table 4.4, has the lowest ash content of 2.9349% followed by sample 1 with a value of 3.0555%. The highest ash content was observed in sample 3 (3.9031%) and sample 5 (3.3714%). This is significant in their burning rate and ignition time. The tolerance level of ash content for fuel is below 4% (Grover *et al.*, 1996).

4.7 FIXED CARBON

Samples 6 and 4 have the highest percentage fix carbon of 94.61% and 94.13% respectively. The high values can be traced to their major components HR, FL and BD which also have high percentage fixed carbon of 82.54%, 75.96% and 87.22% respectively. High fixed carbon implies high calorific value as indicated in Table 4.4. The lowest carbon content was observed in samples 3 and 2 i.e. 92.38% and 93.23% respectively. Samples 3 and 2 have low concentrations of HR and BD as shown in Table 4.3. HR and BD have highest value of fixed carbon being 82.56% and 87.24% respectively.

4.8 CALORIFIC VALUE

The calorific value determines the amount of heat energy present in a material. From Table 4.4, Sample 5 was observed to have the highest calorific value of 24,101.3 kJ/kg which is probably due to the high carbon content and the presence of high FL and CS in the formulation. The particle sizes of the raw materials and the uniform formulation favours attrition and a high degree of conditioning due to its ability to absorb moisture. Sample 1, 6 and 4 also have high calorific values of 20,140.2 kJ/kg, 21,461.8 kJ/kg and 22,141.3 kJ/kg respectively. According to Hutagalung, 2008, the heating value of coal is 24,730 kJ/kg. This indicates that TDB can compete favourably with coal. From Table 4.3 FL and CS are also present in high quantity in sample 4. These waste also have high calorific values of 14,570 kJ/kg and 10,690 kJ/kg shown in Table 4.2. Other manufacturing conditions such as temperature and pressure also influence calorific value (Tumurulu *et al.*, 2010 and Adapa *et al.*, 2003). Samples 2 and 3 had the lower calorific value of 19,821.4 kJ/kg and 18,632.1 kJ/kg respectively. This may be due to the fact that it has low composition of FL even though high amount of the binder. Cassava starch used as binder also influences the properties of the briquette. Cassava starch has a moisture content of 13.09% on dry basis, ash content of 0.24%, a pH of 5.34 and a calorific value of 159.48 kJ/kg or 381 cal/110g (Chitedze *et al.*, 2012).

4.9 COMPRESSIVE STRENGTH

Samples 1, 2 and 3 from Table 4.5, are observed to have the highest compressive strength of 0.2173 kN/cm², 0.1742 kN/cm² and 0.1910 kN/cm² respectively. This is due to the uniform formulation and integration of particles of varying sizes as shown in Table 4.3. HR has particle size of 1.0 mm while that of FL, CS and BD was 0.5mm. According to Grover (1995), a mixture of different particle sizes will give optimum briquette quality

due to high inter-particle bonding with nearly no inter-particle spacing. Samples 5 and 6 have lower compressive strength of 0.1114 kN/cm² and 0.0605 kN/cm². Sample 5 has a higher compressive strength due to its elastic nature influenced by the presence of gelatine collagen fibre in FL and polymeric nature of HR. Sample 6 is brittle and has the lowest compressive strength due to its particle size being larger after calcination. Larger particle size causes cracks and fracture of briquette as well as low fusion points. The recommended particle size for pellet formation is 0.6-0.8mm but there was no available technology to reduce HR to a finer particle size because it was very agile. Compressive strength is one of the most important characteristics of a briquette that determines the stability and durability of the briquette (Kaliyan and Morey, 2010).

Table 4.5: Mechanical Properties of Briquettes

Samples	Weight of Briquette (g)	Bulk Density (kg/cm³)	Compressive Strength (kN/cm²)	Durability Test (Wt %)
1	72.08	0.6984	0.2173	99.23
2	66.01	0.6492	0.1742	99.77
3	68.50	0.6709	0.1910	99.27
4	69.50	0.6410	0.1212	98.94
5	66.74	0.5946	0.1114	98.12
6	71.25	0.7078	0.0605	98.68

4.10 DURABILITY

The durability of briquette is important considering the rigors of handling, transportation, storage and weather conditions of locations where the products will be transported or exported. From Table 4.5, it is observed that sample 2 is the most durable by 99.77% and sample 5 is the least durable by 98.12%. Sample 6 is more durable than sample 5 by a difference of 0.56% even though it has a higher compressive strength. Richard (1990), set an acceptance criterion for durability of sub-bituminous coal briquette as 95%.

4.11 BULK DENSITY

High quality fuel should have high density and strength in order to burn for a longer time and have a higher energy content. The higher the density the higher the compressive strength. From Table 4.5, sample 6 has the highest bulk density of 0.7078kg/cm^3 . The sample is made of carbonised feeds and have a higher carbon content. Sample 1 is next to 6 having a density of 0.6984kg/cm^3 . The sample with the lowest density is 5 having a bulk density of 0.5946kg/cm^3 . The finer the particle size the denser the briquette due to low void. Also the porosity index of fine particles is lower than medium and larger particles (Olorunnisola, 2007).

4.12 IGNITION TIME

The highest ignition time from Table 4.6 was observed in sample 3 at 17 minutes. The ignition time is the time taken for the briquette to ignite with the aid of other energy source like kerosene or gas in small amount. Next to sample 3 are sample 1 and 2 with ignition time of 15 minutes. The least ignition time was observed in sample 6 which is the carbonised sample at 9 minutes. The ignition time is a function of the volatile matter. The higher the volatile matter the higher the ignition time since more time is taken to burn off the volatiles before combustion. Also larger particle size increases ignition time. As seen on the Table 4.6. Samples 4, 5 and 6 have lower ignition times (12 minutes, 13 minutes and 9 minutes respectively) because they have a higher composition of HR with particle size of 1.0mm while samples 1, 2 and 3 have higher ignition times due to the presence of lower particle size (0.5mm) FL and BD. This observation may be adduced to the fact that the larger particle sizes could have more pronounce pore spaces in between the particles than the finer particle size thus favouring the flow of oxygen.

Table 4.6: Energy Evaluation Analysis of Briquettes

Sample	Weight of Briquette (g)	Volume of Water (l)	Ignition Time (min)	Water Boiling Time (min)	Burning Rate (g/min)	Thermal Efficiency %
1	150	100	15	29.35	0.126	21.091
2	150	100	15	32.18	0.122	20.229
3	150	100	17	32.36	0.155	20.707
4	150	100	12	31.00	0.175	20.784
5	150	100	13	29.32	0.169	23.126
6	150	100	9	28.20	0.132	26.376

4.13 WATER BOILING TIME

Water boiling time is a function of the volatile matter, calorific value and TFE. Sample 6 has the least water boiling time at 28.20 minutes followed by sample 5 at 29.32 minutes. According to Onuegbu *et al.*, (2010), it took 26 minutes to boil 100cm³ of water with 100kg of coal. Samples 2 and 3 have the highest water boiling time at 32.18 minutes and 32.36 minutes respectively.

4.14 BURNING RATE

The result of the burning rate of briquettes is shown in Table 4.6. Sample 4 has the fastest burning rate of 0.175g/min followed by sample 5 with burning rate of 0.169g/min. The least burning rate was observed in sample 2 to be 0.122g/min next to sample 1 with 0.126g/min. Sample 6 has a burning rate of 0.132g/min. The burning rate has a significant effect on briquette application. Briquettes with high burning rate implies that more briquette will be required in combustion as they burn off readily. As observed briquette without binder or with little amount of binder burn off faster than those with binder. The particle size also shows inverse proportionality with the briquettes' burning rate.

4.15 THERMAL EFFICIENCY

The thermal efficiency indicates how well energy in the fuel will be converted to heat energy. The optimal thermal efficiency was obtained in sample 6 as 26.376% as shown in Table 4.6. Sample 6 is the carbonised sample. The next highest value was observed in sample 5 which is the sample without binder as 23.125%. Sample 1 also has a higher thermal efficiency of 21.091% than samples 2, 3 and 4 with thermal efficiencies of 20.229%, 20.707% and 20.784% respectively. The lowest thermal efficiency was observed in sample 2. From Table 4.6 it is observed that the higher the thermal efficiency the lower the burning rate of the briquette.

4.16 ECONOMIC ANALYSIS OF SCREW PRESS BRIQUETTE PLANT

The results in Table 4.7 are based upon an exchange rate of 1US\$ = ₦198.90 (LikeForex, 2015), electricity cost at ₦17/kWhr, water at ₦210/m³ and tax rate of 5% (GISTAREA, 2013). The result on Table 4.7 was based on two screw press costing ₦716,040 each having a capacity of 720 kg/hr and a production capacity of 1.44 ton/hr. Plants with less than two machines are not recommended. However, plants with more machines will definitely have better profitability and advantages of scale of operation can be derived. Fixed capital cost and operating costs are the two major cost parameters that make up the plant capital cost. Fixed capital is the cost of the plant ready for start-up. Working capital on the other hand is the extra investment needed over and above the fixed capital to start the plant up and operate it to the point when income is earned. From Table 4.7 the fixed capital cost was ₦4.1 Million which is within the limit of 70% - 95% of total investment cost as required for small capacity plants (Sinnot, 2009). The briquette plant was found to have high fixed cost compared to the raw material cost. The working capital was ₦205,464. This amount was low possibly due to the fact that the machines were fully automated with less

manpower requirement. The total investment needed for a project is the sum of fixed and working capital. Table 4.7 shows that a total of ₦4.3 Million was require as investment to produce 8,460 tonnes of briquettes yearly of which 7,860 tonnes are saleable at ₦696.15 per tonne. From 5% tax, depreciation on machinery and building as (10%) and (5%) respectively, the pay-back period was observed to be within 5 years at the rate of 19% per year. This is the period required after the start of the project to pay off the initial investment from the income. It is often used to judge small improvement of project on operating plant. Payback time is a criterion of investment performance while the return on investment is the ratio of annual profit on investment, and is simply the index of the performance of the money invested. The rate of the return on investment was responsible for the low value of the annual profit of ₦781,876 (without taxes and depreciation) for the plant.

Table 4.7: Economic Evaluation Result

ECONOMIC VARIABLES	VALUES
Capacity (ton)	8,460
Fixed Capital (₦)	4,110,269
Working Capital (₦)	205,464
Total Investment (₦)	4,315,733
Variable Cost (₦)	579,595
Annual Production Cost (₦)	4,689,864
Production Cost/ton (₦)	120,335
Annual Profit (₦)	781,876
Pay Back Period (Years)	5.6
Return on Investment (%)	19

4.17 COMPARATIVE COSTS OF BRIQUETTES WITH OTHER FUELS

The urban or peri-urban market appears to be the most promising for expanding a business. Here there are sufficient consumers who already pay for fuel and have briquette- compatible heating and cooking equipment. In rural areas, neither is guaranteed. Table 4.8 shows the cost, energy value and quality of other fuel source used in rural areas in comparison with briquette. Low smoke production is a requirement for urban users which carbonised briquettes can meet. Non-carbonised briquettes were generally found to be less desirable, except in areas where smoke can easily be dispersed e.g. businesses/schools using a stove with a chimney.

About 14 kg of briquette was used to generate equivalent amount of energy (30MJ) from 0.79 kg, 1.0 kg and 2.7 kg of kerosene, coal and firewood respectively. The quality of heat generated from the briquette was better than kerosene, coal and firewood in terms of burning length and smoke emission. Firewood produced heat with the highest intensity but can only be used in mediums where there is a control alternative source of smoke dispersion.

The price of briquette increases further its competitive strength with other fuel source. It is likely that competitive prices would lead to increased demand from urban areas, displacing a significant fraction of charcoal use in these areas.

Table 4.8: A Comparison of the Characteristics of Domestic Energy Fuels

Quality Considered	Briquette	Kerosene	Coal	Firewood
Energy	13.54kg ≈ 30 MJ	0.83kg ≈ 30 MJ	0.97kg ≈ 30MJ	3.14 kg ≈ 30MJ
Price (₦)	8.40	39.00	15.55	7.00
Relative Heat Intensity	Low	Variable	Moderate	High
Relative Burning Rate	High	Variable	Moderate	Low

Smoke Emission	Low	None	Low	high
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Table 4.9 shows the percentage of households in Hayin Danyaro and Zango in Samaru, Zaria using different types of fuel.

N = 40 (Number of houses)

From survey, residence from Hayin Danyaro and Zango uses less of firewood even when it appeared to be the cheapest fuel available. This is probably due to the high smoke emission resulting in dark soot on cooking utensils and cooking areas. Residence in Zango used liquefied petroleum gas more often than residence in Hayin Danyaro but the consumption was 20% the consumption of firewood and kerosene. This they said was due to the high cost of the fuel and cooking appliances. The consumption of wood charcoal and kerosene was very high in both areas and relatively at the same rate.

Table 4.9: Comparative Percentage Consumption of Other Fuels

Types of fuel	Hayin Danyaro	Zango
Wood Charcoal %	83	90
Kerosene %	84	78
LPG %	9	16
Fire Wood %	4.5	6

Some households use more than one type of fuel. Wood charcoal and firewood are very commonly used for lunch and dinner among those houses of low income earners. 56% - 35% of households purchase 2kg units and 90kg bags respectively while the rest bought in 4kg units.

Table 4.10: Cost Evaluation of Wood Charcoal per Bag

	Hayin Danyaro	Zango
Monthly Bags weighing 90kg	1.4	1.2
Cost at ₦ 1400 per bag	₦ 1,960	₦1,680
Bags per year	16.8	14.4
Cost per year	₦ 2,3520	₦ 2,0160

It was estimated that on average households used 1.4 Tonnes of wood charcoal per year with an annual cost of ₦ 21,840. If we assume that about 60% of the 600,000 households in Nigeria live in similar conditions to those in Hayin Danyaro and Zango, with similar charcoal usage, then almost 500,000 tons of charcoals are being used annually by Nigeria's low income residents, with an expenditure of nearly 7.8billion Naira i.e. US\$49M compared to US\$1.75M if the briquettes produced from tannery solid waste.

4.17.1 Institutions/Business Enterprises

From the 21 food vendors that responded to the question on use of wood charcoal, it was established that they consumed on average eleven 90kg bags per month while the 7 education/charity organizations consumed 2 bags per month on average. From the data provided in Table 4.10, these translates to ₦18,200 or (US\$114) annually. Eighty two percent of institutions/enterprises purchased their charcoal in 90kg bags.

4.17.2 Commercialization/Market Survey

The survey showed that 96% of female respondents and 86% of male respondents were willing to switch over to using fuel briquettes to meet their cooking and heating needs. The identified preferred qualities were; length of burning time, high thermal heat, less smoke and shorter time to ignite. The low income households chose local charcoal dealers as the outlets while middle income households selected supermarkets as outlets for the

briquettes. Both men and women from low income households preferred small packages of four pieces while those from the middle income households wished to buy large packages containing 50 pieces.

Once quality is assured, fuel briquettes is a potential substitute for wood charcoal which could be widely adopted among urban households where, for instance, over 80% of interviewed households in both poor and middle income neighbourhoods were found to use wood charcoal, the majority of them using it to prepare main meals, namely, lunch and dinner. Institutions/business enterprises such as schools and food kiosk are other potential customers of briquettes. Alternatively consumers were convinced to use briquettes when they found out they burned for longer time periods, despite being more expensive per unit i.e. if the cost per hour of burn time worked out lower than competitive products.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Tannery derived briquette was formulated using tannery solid waste (fleshing, hair, chrome shavings and buffing dust).

Factors found to affect the quality of the briquette included; particle size, presence of a binder, moisture content, volatile matter, ash content, calorific value, density and compression strength. The moisture content, volatile matter, ash content and calorific values ranged from 0.3807 - 1.2615%, 1.8409 - 2.7664%, 2.9343 - 3.9031%, and 17,461.8 – 24,101.3 kJ/kg, respectively.

The tannery derived briquette energy values were found to be within the range of 17,461.8 – 24,101.3kJ/kg which is comparable to energy value to other fuel sources such as sub-bituminous coal with values in the range of 20,000 – 24,730 kJ/kg.

Feasibility studies indicate that tannery briquette production is a viable venture. Briquette production plant with 8,460 tons capacity will require a total investment of ₦3,732,056 and pay-back period will be within five years at the rate of about 19% per year.

5.2 RECOMMENDATIONS

The energy within tannery solid waste should be utilised to satisfy the high demand for heat and electricity requirements contributing to a large proportion of the operational expenditure in most industries.

Environmental Impact Assessment should be carried out on briquette to ascertain the impact on the environment and health.

Further investigation on quality enhancement of briquette such as blending the solid

waste with other biomass or coal dust should be carried out.

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APPENDICES

Our Ref. NIRR-1/3C/14/01

The analytical results of instrumental neutron activation analysis of Four (4) Biological samples for IMEH ETIM ONUKAK are presented below. The reported uncertainty was calculated mainly from counting statistics and is not the normal standard deviation on replicate analyses.

Date: 2014-08-07

Nuclear Science and Technology Section
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A SUMMARY OF ANALYTICAL RESULT

ELEMENT	A	B	C	D
Mg	BDL	6770 ± 528	BDL	BDL
Al	122 ± 9	15190 ± 198	2129 ± 134	9612 ± 87
Cl	2007 ± 32	4118 ± 58	68580 ± 274	1612 ± 34
Ca	3055 ± 238	372300 ± 3351	31440 ± 1321	650 ± 126
V	BDL	13.4 ± 1.3	60.6 ± 3.4	8.7 ± 0.7
Mn	4.7 ± 0.1	157 ± 1	NA	5.8 ± 0.1
Na	2413 ± 10	5820 ± 12	6562 ± 7	3054 ± 9
Sr	BDL	383 ± 21	NA	BDL
K	663 ± 114	1259 ± 180	BDL	BDL
La	BDL	1.5 ± 0.1	BDL	7.1 ± 0.2
Sm	BDL	0.16 ± 0.02	0.22 ± 0.05	0.94 ± 0.04
Sc	0.09 ± 0.01	0.51 ± 0.02	0.43 ± 0.02	1.15 ± 0.02
Cr	19.9 ± 0.3	46.7 ± 0.5	4909 ± 5	4441 ± 4
Fe	387 ± 40	4153 ± 75	903 ± 57	836 ± 50
Co	BDL	0.23 ± 0.02	0.08 ± 0.02	0.16 ± 0.02
Zn	82 ± 5	187 ± 6	33 ± 4	29 ± 3
Br	1.8 ± 0.2	1.1 ± 0.2	9.4 ± 0.3	0.9 ± 0.1
Rb	6 ± 2	6.5 ± 1.5	BDL	4.7 ± 1.4
Sb	BDL	BDL	0.031 ± 0.005	BDL
Ba	BDL	56 ± 13	BDL	BDL
Eu	BDL	BDL	BDL	0.21 ± 0.04
Yb	BDL	0.34 ± 0.06	BDL	BDL
Th	BDL	0.12 ± 0.01	0.21 ± 0.04	0.16 ± 0.03

All results are in mg/kg (milligram per kilogram)

BDL: Below Detection Limit

NA: Not Analysed

Please contact the undersigned for further clarification


 Professor M. O. A. Oladipo
 (Head of Section)

Above is the Neutron Activation Analyser result of raw sample

A PROXIMATE ANALYSIS

Samples	Weight of Crucible (g)	Weight of Sample (g)	Weight of Crucible + sample (g)	1st Reading (g)	2nd Reading (g)	3rd Reading (g)	4th Reading (g)
Hair	41.16	3	44.16	43.44	42.18	41.96	41.96
Fleshing	43.25	3	46.25	45.34	44.65	43.15	43.13
Chrome Shaving	35.98	3	38.98	38.28	36.87	36.68	36.68
Buffing Dust	43.84	3	46.84	46.52	46.49	46.38	46.36

A1 Percentage Moisture Content (PMC) of raw samples on dry basis

$$PMC = \frac{A-B}{A} \times 100$$

Where A is the initial weight and B is the constant weight of the sample in a furnace at 110⁰C.

$$\text{Hair; } PMC = \frac{44.16-41.96}{44.16} \times 100$$

$$= \frac{2.2}{44.16} \times 100$$

$$= 4.982\%$$

$$\text{Fleshing; } PMC = \frac{46.25-43.13}{46.25} \times 100$$

$$= \frac{3.12}{46.25} \times 100$$

$$= 6.750\%$$

$$\text{Chrome Shaving; PMC} = \frac{38.98 - 36.68}{38.98} \times 100$$

$$= \frac{2.3}{38.98} \times 100$$

$$= 5.900\%$$

$$\text{Buffing Dust; PMC} = \frac{46.84 - 46.36}{46.84} \times 100$$

$$= \frac{0.48}{46.84} \times 100$$

$$= 1.023\%$$

A2 Percentage Volatile Matter (PVM) of raw samples

$$\text{PVM} = \frac{A-B}{A} \times 100$$

Where; A is the weight of the oven-dried sample and B is the weight of the sample after 10 min in the furnace at 550°C.

$$\text{Hair; PVM} = \frac{41.96 - 37.89}{41.96} \times 100$$

$$= \frac{4.07}{41.96} \times 100$$

$$= 9.699\%$$

$$\text{Fleshing; PVM} = \frac{43.13 - 36.88}{43.13} \times 100$$

$$= \frac{6.25}{43.16} \times 100$$

$$= 14.500\%$$

$$\text{Chrome Shaving; PVM} = \frac{36.68 - 32.98}{36.68} \times 100$$

$$= \frac{3.7}{36.68} \times 100$$

$$= 10.087\%$$

$$\text{Buffing Dust; PVM} = \frac{46.36 - 42.00}{46.36} * 100$$

$$= \frac{4.36}{46.36} * 100$$

$$= 9.405\%$$

A3 Percentage Ash Content (PAC) of raw samples

$$\text{PAC} = \frac{c}{A} * 100$$

Where c is the weight of the ash after 60min in a furnace at 450⁰C

$$\text{Hair: PAC} = \frac{43.16 - 41.96}{43.16} * 100$$

$$= \frac{1.20}{43.16} * 100$$

$$= 2.78\%$$

$$\text{Fleshing: PAC} = \frac{45.77 - 44.19}{45.77} * 100$$

$$= \frac{1.58}{45.77} * 100$$

$$= 3.45\%$$

$$\text{Chrome Shaving: PAC} = \frac{38.36 - 37.39}{38.36} * 100$$

$$= \frac{0.967}{38.36} * 100$$

$$= 2.53\%$$

$$\text{Buffing Dust: PAC} = \frac{46.02 - 44.94}{46.02} * 100$$

$$= \frac{1.08}{46.02} * 100$$

$$= 2.35\%$$

A4 Percentage Fixed Carbon (PFC) of raw samples

$$\text{PFC} = 100 - (\text{PVM} + \text{PAC} + \text{PMC})$$

Hair; $\text{PFC} = 100 - (4.982 + 9.699 + 2.78)$

$$= 82.54\%$$

Fleshing; $\text{PFC} = 100 - (6.75 + 14.500 + 3.45)$

$$= 75.96\%$$

Chrome Shaving; $\text{PFC} = 100 - (5.900 + 10.087 + 2.53)$

$$= 81.48\%$$

Buffing Dust; $\text{PFC} = 100 - (1.023 + 9.405 + 2.35)$

$$= 87.224\%$$

Samples	Weight of Crucible (g)	Weight of Sample (g)	Weight of Crucible + sample (g)	1st Reading (g)	2nd Reading (g)	3rd Reading (g)	4th Reading (g)
1	36.45	3	39.45	39.38	39.28	39.1	39.18
2	36.83	3	39.83	39.78	39.72	39.6	39.62
3	35.54	3	38.40	38.33	38.18	38.0	38.05
4	36.48	3	39.48	39.32	39.16	39.0	39.05
5	37.21	3	40.53	40.21	40.05	39.7	39.70
6	36.67	3	40.56	39.67	39.54	39.5	39.52

A5 Percentage Moisture Content of Briquettes

Sample 1; $\text{PMC} = \frac{39.45 - 39.18}{39.45} \times 100$

$$= \frac{0.27}{39.45} \times 100$$

$$= 0.6844\%$$

$$\text{Sample 2; PMC} = \frac{39.83 - 39.62}{39.83} \times 100$$

$$= \frac{0.21}{39.83} \times 100$$

$$= 0.5272\%$$

$$\text{Sample 3; PMC} = \frac{38.40 - 38.03}{38.40} \times 100$$

$$= \frac{0.37}{38.40} \times 100$$

$$= 0.9656\%$$

$$\text{Sample 4; PMC} = \frac{39.48 - 39.05}{39.48} \times 100$$

$$= \frac{0.43}{39.48} \times 100$$

$$= 1.0892\%$$

$$\text{Sample 5; PMC} = \frac{40.21 - 39.70}{40.21} \times 100$$

$$= \frac{0.51}{40.21} \times 100$$

$$= 1.2683\%$$

$$\text{Sample 6; PMC} = \frac{39.67 - 39.52}{39.67} \times 100$$

$$= \frac{0.15}{39.67} \times 100$$

$$= 0.3781\%$$

A6 Percentage Volatile Matter of Briquettes

$$\text{Sample 1; PVM} = \frac{39.18 - 38.33}{39.18} \times 100$$

$$= \frac{0.85}{39.18} \times 100$$

= 2.1695%

$$\text{Sample 2; PVM} = \frac{39.62 - 38.72}{39.62} * 100$$

$$= \frac{0.90}{39.62} * 100$$

= 2.2716%

$$\text{Sample 3; PVM} = \frac{38.03 - 36.98}{38.03} * 100$$

$$= \frac{1.05}{38.03} * 100$$

= 2.7610%

$$\text{Sample 4; PVM} = \frac{39.05 - 38.33}{39.05} * 100$$

$$= \frac{0.72}{39.05} * 100$$

= 1.8438%

$$\text{Sample 5; PVM} = \frac{39.70 - 38.85}{39.70} * 100$$

$$= \frac{0.85}{39.70} * 100$$

= 2.1411%

$$\text{Sample 6; PVM} = \frac{39.52 - 38.77}{39.52} * 100$$

$$= \frac{0.75}{39.52} * 100$$

= 1.8978%

A7 Percentage Ash Content (PAC) of briquettes

$$\text{Sample 1; PAC} = \frac{39.51 - 37.97}{39.51} * 100$$

$$= \frac{1.54}{39.51} * 100$$

= 3.9031%

$$\text{Sample 2; PAC} = \frac{40.18 - 38.92}{40.18} * 100$$

$$= \frac{1.26}{40.18} \times 100$$

$$= 3.1402\%$$

$$\text{Sample 3; PAC} = \frac{40.24 - 39.01}{40.24} \times 100$$

$$= \frac{1.23}{40.24} \times 100$$

$$= 3.0555\%$$

$$\text{Sample 4; PAC} = \frac{40.37 - 39.19}{40.37} \times 100$$

$$= \frac{1.185}{40.37} \times 100$$

$$= 2.9349\%$$

$$\text{Sample 5; PAC} = \frac{40.53 - 39.27}{40.53} \times 100$$

$$= \frac{1.261}{40.53} \times 100$$

$$= 3.1105\%$$

$$\text{Sample 6; PAC} = \frac{39.82 - 38.48}{39.82} \times 100$$

$$= \frac{1.342}{39.82} \times 100$$

$$= 3.3714\%$$

A8 Percentage Fixed Carbon of Briquettes

$$\text{Sample 1; PFC} = 100 - (0.6844 + 2.1695 + 3.0555)$$

$$= 94.09\%$$

$$\text{Sample 2; PFC} = 100 - (0.5272 + 2.2716 + 3.1402)$$

$$= 94.06\%$$

$$\text{Sample 3; PFC} = 100 - (0.9656 + 2.7610 + 3.9031)$$

= 92.38%

Sample 4; PFC = 100 - (1.0892 + 1.8438 + 2.9349)

= 94.13%

Sample 5; PFC = 100 - (1.2683 + 2.1411 + 3.3714)

= 93.22%

Sample 6; PFC = 100 - (0.3781 + 1.8978 + 3.1105)

= 94.61%

B MECHANICAL ANALYSIS

B1 Durability of Briquettes

Samples	Mesh Size (mm)	Time (min)	rpm	Initial Weight (Kg)	Final Weight (kg)
1	5	10	50	66.23	65.71
2	5	10	50	67.98	67.82
3	5	10	50	69.87	69.36
4	5	10	50	67.85	67.13
5	5	10	50	71.34	69.99
6	5	10	50	73.04	72.08

$$\text{Durability} = \left(\frac{\text{Mat}}{\text{Mbt}} \right)$$

Where *Mat* is the mass of the briquettes retained on the screen after tumbling (kg), and *Mbt* is the mass of the briquettes retained on the screen before tumbling (kg).

$$\text{Sample 1; Durability} = \frac{65.71}{66.23} \times 100$$

= 99.22%

$$\text{Sample 2; Durability} = \frac{67.82}{67.98} \times 100$$

= 99.77%

$$\text{Sample 3; Durability} = \frac{69.36}{69.87} \times 100$$

= 99.27%

$$\text{Sample 4; Durability} = \frac{67.13}{67.85} \times 100$$

= 98.94%

$$\text{Sample 5; Durability} = \frac{69.99}{71.34} \times 100$$

= 98.12%

$$\text{Sample 6; Durability} = \frac{72.08}{73.04} \times 100$$

= 98.68%

B2 Density of Briquettes

Samples	Force (kN)	π	Radius (cm)	(Radius) ² (cm ²)	Height (cm)	Area (cm ²)	Volume (cm ³)	Mass (kg)
1	2.80	3.142	2.025	4.101	8.01	12.88	103.2015	72.08
2	2.20	3.142	2.005	4.020	8.05	12.63	101.6783	66.01
3	2.40	3.142	2.000	4.000	8.07	12.57	101.4238	68.05
4	1.60	3.142	2.050	4.203	8.21	12.57	108.4198	69.50
5	1.40	3.142	2.050	4.203	8.50	13.21	112.2495	66.74
6	0.80	3.142	2.000	4.000	8.01	12.57	100.6697	71.25

$$\text{Density} = \frac{m}{V}$$

Where m is the weight of the sample, V is volume of the sample

$$\text{Sample 1; Density} = \frac{72.08}{103.2015}$$

$$= 0.6984 \text{kg/cm}^3$$

$$\text{Sample 2; Density} = \frac{66.01}{101.6783}$$

$$= 0.6492 \text{kg/cm}^3$$

$$\text{Sample 3; Density} = \frac{68.05}{101.4238}$$

$$= 0.6709 \text{kg/cm}^3$$

$$\text{Sample 4; Density} = \frac{69.50}{108.4198}$$

$$= 0.6410 \text{kg/cm}^3$$

$$\text{Sample 5; Density} = \frac{66.74}{112.2495}$$

$$= 0.5946 \text{kg/cm}^3$$

$$\text{Sample 6; Density} = \frac{71.25}{100.6697}$$

$$= 0.7078 \text{kg/cm}^3$$

C ENERGY EVALUATION ANALYSIS

C1 Thermal Fuel Efficiency (TFE) of Briquettes

Samples	M _w	C _p	L	T _o	T _b	M _c	M _f	E _f
	(kg)	(kJ/kgK)	(kcal/kg)	(K)	(K)	(kg)	(kg/10 ³)	(kJ/kg)
1	0.15	0.0143	540	300	365	0.0174	2.2193	20140.2
2	0.15	0.0143	540	300	358	0.0154	2.0936	19821.4
3	0.15	0.0143	540	298	359	0.0155	2.1965	18632.1
4	0.15	0.0143	540	297	364	0.0169	2.0030	22141.3
5	0.15	0.0143	540	296	366	0.0177	1.7232	24101.3
6	0.15	0.0143	540	300	368	0.0178	2.1084	17461.8

$$\text{TFE} = \frac{M_w C_p (T_b - T_o) + M_e L}{M_f E_f} \times 100\%$$

M_w = mass of water (kg)

C_p = specific heat of water (kJ/kgK)

T_b = boiling temperature of water (K)

T_o = initial temperature of water (K)

M_e = mass of water evaporated (kg)

L = latent heat of evaporation (kcal/kg)

M_f = mass of fuel burnt (kg)

E_f = calorific value of fuel kJ/kg)

$$\text{Sample 1; TFE} = \frac{0.10134 \times 0.0143(365-300) + 0.01744(540)}{2.2193 \times 10^{-3} \times 20140.2} \times 100\%$$

$$= \frac{9.4196 \times 10^{-3} + 9.4176}{44.6971}$$

= 21.091%

$$\text{Sample 2; TFE} = \frac{0.10134 \times 0.0143(358-300) + 0.01539(540)}{2.0936 \times 10^{-3} \times 19821.4} \times 100\%$$

$$= \frac{0.0841 + 8.3947}{41.4981}$$

= 20.229%

$$\text{Sample 3; TFE} = \frac{0.10134 \times 0.0143(359-298) + 0.01553(540)}{2.1965 \times 10^{-3} \times 18632.1} \times 100\%$$

$$= \frac{0.0884 + 8.3862}{40.9263}$$

= 20.707%

$$\text{Sample 4; TFE} = \frac{0.10134 \times 0.0143(364-297) + 0.01689(540)}{2.0030 \times 10^{-3} \times 22141.3} \times 100\%$$

$$= \frac{0.0971 + 9.2177}{44.3499}$$

$$= 20.784\%$$

$$\text{Sample 5; TFE} = \frac{0.10134 \times 0.0143(366 - 296) + 0.01766(540)}{1.7232 \times 10^{-3} \times 24101.3} \times 100\%$$

$$= \frac{0.1014 + 9.5364}{41.6753}$$

$$= 23.126\%$$

$$\text{Sample 6; TFE} = \frac{0.10134 \times 0.0143(368 - 300) + 0.01780(540)}{2.1084 \times 10^{-3} \times 17461.8} \times 100\%$$

$$= \frac{90.0985 + 9.6120}{36.8158}$$

$$= 26.376\%$$

C2 Burning Rate of Briquettes

Samples	W _T	W _S	W _T + W ₁	W ₂	t ₀	t ₁	t ₂	Δt	
	(g)	(g)	WS (g)	(g)	(g)	(mim)	(mim)	(mim)	(mim)
1	33.80	10	43.80	38.31	35.49	11:18	11:38	12:24	66.00
2	33.77	10	43.77	32.77	34.86	13:15	13:52	14:38	73.00
3	35.44	10	45.44	39.79	37.38	10:23	10:40	11:15	52.00
4	34.28	10	44.28	37.22	36.23	11:30	11:48	12:17	46.00
5	35.16	10	45.16	38.48	36.89	14:46	14:57	15:35	49.00
6	35.24	10	45.24	39.54	37.06	14:38	14:47	15:40	62.00

$$B_s = \frac{Q_1 - Q_2}{T}$$

B_s = burning rate (g/min)

Q₁ = initial weight of fuel prior to burning (g) = W_T + W_S

Q_2 = final weight of fuel prior to burning (g) = W_2

T = total burning time (min) =

$\Delta t = W_T$ = weight of wire (g)

W_S = weight of sample (g)

$$\text{Sample 1; } B_s = \frac{43.80 - 35.49}{66}$$

$$= \frac{8.32}{66}$$

$$= 0.126 \text{ g/min}$$

$$\text{Sample 2; } B_s = \frac{43.77 - 34.86}{73}$$

$$= \frac{8.28}{73}$$

$$= 0.169 \text{ g/min}$$

$$\text{Sample 3; } B_s = \frac{45.44 - 37.38}{52}$$

$$= \frac{8.91}{52}$$

$$= 0.122 \text{ g/min}$$

$$\text{Sample 4; } B_s = \frac{44.28 - 6.23}{46}$$

$$= \frac{8.06}{46}$$

$$= 0.155 \text{ g/min}$$

$$\text{Sample 5; } B_s = \frac{45.16 - 36.88}{49}$$

$$= \frac{8.05}{49}$$

$$= 0.175 \text{ g/min}$$

$$\text{Sample 6; } B_s = \frac{45.24 - 37.06}{62}$$

$$= \frac{8.18}{62}$$

$$= 0.132 \text{ g/mim}$$

D ECONOMIC EVALUATION ANALYSIS

D1 System Material Balance

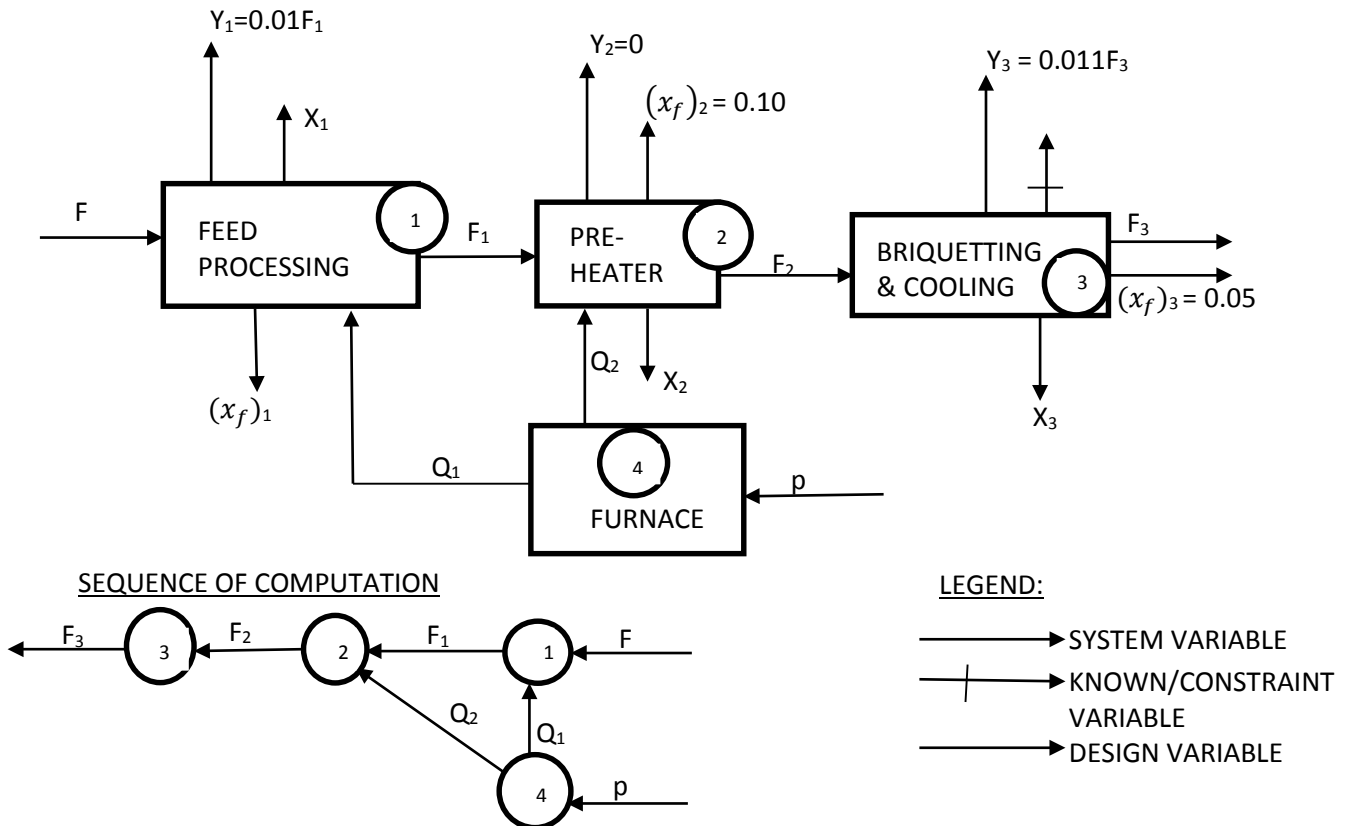


Figure I: Process Flow Diagram for Briquette Production Using a Screw Press

With reference to Figure I the overall material balance is given by the following equation:

$$F - \sum_1^3 X, Y - P = P \left(\frac{\text{kg}}{\text{hr}} \right)$$

where; F feed rate with x_f moisture content

$X_{1,2,3}$ moisture loss from components 1, 2 and 3

$Y_{1,2,3}$ material loss from components 1, 2, and 3

p amount of briquette used in furnace (this can be reduce to the extent of f_5 ,

an extra fuel instead of briquette)

P net production of briquettes

$(x_f), (x_f)_1, (x_f)_2, (x_f)_3$ moisture content of different streams on wet basis.

1. Feed Processing Subsystem (1)

Basis: F kg/hr of wet feed containing X_f fraction of moisture on wet basis.

Input = F with X_f moisture content

Assuming 1% loss of material at $(x_f)_1$ moisture content,

Output (F_1) = 0.99 (F - X_1) with $(x_f)_1$ moisture content

Loss of material = Y_1 = 0.01 (F - X_1) with $(x_f)_1 = 0.1$ moisture content,

Where X_1 is the loss of moisture

If x_1 is 0.1, no drying is required. If $x_1 > 0.1$ drying is required.

In the case of drying;

Loss of moisture $X_1 = x_1 * F - 0.1 (F - X)$

$$X_1 = (x_f - 0.1F)/0.9 = F(1.11x_f - 0.111) \quad (D.1)$$

Where; $x_f = 0.1$, then X_1 is equal to zero. This means no drying is required.

Substituting the value of X_1 ,

$$F_1 = 1.0989F(1 - x_f) \quad (D.2)$$

2. Preheating Subsystem (2)

In this section the biomass is heated to about 60⁰C. About 2% loss of moisture i.e. from 10% to 8% is expected.

Input $(F_1) = 0.99(F - X_1)$ with $(x_f)_1 = 0.1$ moisture content.

$$\begin{aligned} \text{Loss of moisture} &= X_2 = F_1 * (x_f)_1 - (F_1 - X_2) (x_f)_2 \\ F_1 &= 0.99(F - X_1); (x_f)_1 = 0.1; (x_f)_2 = 0.08 \end{aligned} \quad (\text{D.3})$$

$$X_1 = (1.11x_f - 0.111)F \quad (\text{D.4})$$

Substituting these values in eqn. D.2,

$$X_2 = 0.0239F(1 - x_f)$$

$$\text{Output } (F_2) = 0.99(F - X_1) - X_2$$

$$F_2 = 1.075F(1 - x_f)$$

3. Briquetting and Cooling Subsystem

During processing of biomass in this subsystem, the moisture is further reduced from 8% to 5% and 11 gm/kg of briquette is converted into volatile fumes i.e. 1.1% loss of material having 5% moisture.

$$\text{Input } (F_2) = 1.075F(1 - x_f)$$

$$\text{Loss of moisture } X_3 = (x_f)_2 * F_2 - (F_2 - X_3) (x_f)_3$$

$$(x_f)_2 = 0.08 \text{ and } (x_f)_3 = 0.05$$

$$X_3 = 0.034F(1 - x_f) \quad (\text{D.6})$$

$$\text{Output } (F_3) = F_2 - X_3 - 0.011F_3 \text{ Or,}$$

$$F_3 = (F_2 - X_3)/1.011$$

$$\text{Substituting the values of } F_2 \text{ and } X_3, F_3 = 1.0297 (1 - x_f)F \quad (\text{D.7})$$

Production: $P = F_3 - p$ (with $(x_f)_3 = 0.05$ moisture content), where p is the amount of briquettes used (if any) in the furnace.

4. Furnace (4)

One has the option to burn either faulty briquettes or large size wood/biomass in the

furnace. Assuming that p kg/hr of briquettes having heating value of h kcal/kg are only used in the furnace, the value of p will depend upon whether heat produced is used only for preheating or both for preheating and drying of biomass. While heat from the furnace is transferred to the preheater (2) indirectly through hot oil as heat transfer medium, the drying is done directly by mixing flue gases with the feed biomass in the processing unit (1).

D2 AMOUNT OF BRIQUETTES FOR FURNACE (ENERGY BALANCE)

A. Case I Preheating

The furnace is used only for preheating. The material is heated up to 100°C and there is loss of moisture from 10% in feed to 8% in the product.

$$\text{Heat required in preheater} = Q_2 = F_1 * 0.37(100 - 30) + X_2 * 560$$

[0.37 is the specific heat of biomass with 10% moisture]

$$\text{Or, } Q_2 = 25.9F_1 + 560X_2$$

Substituting the value of F_1 (eqn. D.2) and X_2 (eqn. D.4 and $X_1 = 0.1$)

$$Q_2 = 37.68 F \quad (\text{D.8})$$

Assuming 50% heat going for preheating and the remaining 50% accounted for by losses in flue gases (40%) and losses due to radiation in oil circulating system (10%), heat required in furnace,

$$Q_4 = 37.68F/0.5 = 75.36F \quad (\text{D.8.1})$$

Assuming 90% combustion efficiency of furnace which takes into consideration the radiation losses from furnace and uncombusted fuel, the amount of briquettes required in furnace for preheating having heating value of h kcal/kg

$$p = 75.36F/0.9h = 83.7F/h \quad (\text{D.9})$$

B. Case II Preheating and Drying

Heat required for drying = Q_1

Feed = F kg/hr; initial moisture = x_1

Final moisture = 10% or $(x_f)_1 = 0.1$

Surface temperature = 50°C (according to plant data)

$$Q_1 = F(1 - x_f) \cdot 0.3 \cdot (50 - 30) + x_f F(50 - 30) + 514X_1$$

= Dry feed sensible heat + Sensible heat of water + Latent heat

Putting $X_1 = F(1.11x_f - 0.111)$ in eqn. 5.4,

$$Q_1 = F(584x_f - 51)$$

This heat is needed in flue gases. Since flue gas heat is also available from preheating activity, this must be deducted.

Heat already available is 40% of Q_4

i.e., $0.4 \cdot 7575.36F = 30.144F$ (eqn. 8.1)

$$\text{Net extra heat} = F(584x_f - 51) - 30.144F$$

$$= F(584x_f - 81.144) \quad (\text{D.10})$$

Assuming 40% heat utilization for drying,

$$\text{Heat required in flue gasses} = F(1460x_f - 202.8)$$

Assuming 90% combustion efficiency and fuel with h kcal/kg heating value (as in case I),

$$\text{amount of briquettes required for drying} = F(1460x_f - 202.8)/0.9h$$

$$\text{Or, } = \frac{F(1622.2x_f - 225.3)}{h} \text{ kg/hr}$$

(D.10.1)

Amount of briquettes required both for drying and preheating (p)

$$p = \frac{F(1622.2x_f - 225.3 + 83.70)}{h} \text{ kg/hr}$$

$$p = \frac{F(1622.2x_f - 141.6)}{h} \text{ kg/hr} \quad (\text{D.11})$$

D3 Material and Energy Balance

Basis: Two machines each of 720 kg/hr (briquette size is 80mm)

Production capacity, $F_3 = 1440 \text{ kg/hr}$

Briquette consumed (CV 4200 kcal/kg)

From eqn. D.9, Briquettes consumed = $(83.7 \times 1440)/4200 = 28.697 \approx 29 \text{ kg/hr}$

Net production = $1440 - 30 = 1410 \text{ kg/hr}$

Feed required (eqn. 5.7) = $F_3/1.0297 (1-x_f)$

$$F = 1553.9 \approx 1554 \text{ kg/hr}$$

Thermal energy input (in the furnace)

$$h = 4200 \times 30 = 126000 \text{ kcal/hr}$$

D4 Machinery and Electrical Power Input

Total power installed is 215 hp or 160.33 kW. With utilization factor of 0.7, the power input of the plant is 114 kW. Assuming a 1.44 T/hr production rate, the electrical power input amounts to 76.2 kW per tonne. However, during smooth briquette operations, the die heaters are not in use for most of the time.

Assuming energy inputs for one tonne of briquettes having $4200 \times 10^3 \text{ Kcal}$ of intrinsic energy as:

Electrical = 76.2 kWh or 65,500 Kcal

Thermal = $20 \times 4200 = 84,000 \text{ Kcal}$

The percentage of electrical energy input in briquetting = 1.5
in addition to thermal input = 2.0

D4.1 Manpower Requirement

The managerial and operations staff required for a briquetting plant depend upon the capacity of the unit and number of operating hours per day. As regards to operating hours, it is absolutely essential that capacity utilization should be as high as possible. One would expect 85% capacity utilization with 300 working days in a year. Large units with more than 4 units may run 2 shifts /day and still make profit but small units with 2 machines have to operate 20-22 hrs/day. Further, smaller units having limited profitability cannot afford to hire the services of highly paid managers. Such units should be managed either by the entrepreneurs themselves or the services of existing management with the main industries (in case of ancillary unit) should be made available to the briquetting unit. As far as possible, the supply of raw materials and the sales of briquettes should be sub contracted so that the entrepreneur/manager can concentrate their efforts solely on running the production unit.

Manpower requirement for a 2 machine unit having capacity to produce 1.3 to 1.44 tonnes/hour of briquettes are as shown in the below;

No. of staff	Job description	Wages (₦)	Total (₦)
1	Plant supervisor	70,000	70,000
1	Accountant	60,000	60,000
1	Clerical staff	50,000	50,000
3	Shift technician	50,000	150,000
2	Maintenance technician	50,000	100,000
3	Semi-skilled machine operator	30,000	90,000
12	Labourers	30,000	360,000
2	Watchman	15,000	30,000

The above listed staff are only indicative and actual deployment will depend on the specific location of the plant and degree of automation incorporated into the plant. For example, deployment of a small size loader would change the staffing pattern. If the feed is regularly produced by the main tannery industry, a small feeding bin will eliminate the need for labourers feeding the raw material. All these functions have to be carefully considered in a project feasibility report and each report is highly site specific.

D4.2 Infrastructural Facilities

Power	150 kw
Land area	450 m ²
Operational shed area	240 m ²
Briquetting storage	240 m ²

D5 Economic Analysis of Briquetting

Cost analysis of a briquetting plant is highly biomass and site specific and depends on the number of machines deployed in the plant. Therefore, it is imperative that a feasibility

report should be prepared for each briquetting unit before its installation.

D5.1 Typical Cost Analysis

A typical cost analysis with materials which are available in dry form and do not therefore require drying but do need grinding prior to briquetting is given below.

Capacity

Basis:

Two machines each 720 kg/hr

Production capacity = 1.44 T/hr (20 hrs/day operation)

Operating days per year	300
Operating hours per year	6000
Capacity utilization	85%
Raw material	8000 (TPY)
Moisture losses	350 (TPY)
Briquettes produced	8460 (TPY)
Briquettes consumed (Dryer)	600 (TPY)
Saleable production	7860 (TPY)

D5.1.1 Fixed Capital

1. Purchase Cost of Equipment (PCE) = ₦1.3M i.e. total cost of equipment

2. Physical Plant Cost (PPC) = (1+ f1 + ...+ fi)

f1 equipment erection	0.4
f2 instrumentation	0.2
f3 piping	0.7

f4 electrical	0.1
f5 utilities	0.5
f6 storage	0.15
f7 contingency	0.01

$$\text{PPC} = \text{₹ } 1,312,740 (1 + 0.4 + 0.2 + 0.7 + 0.1 + 0.5 + 0.15)$$

$$= \text{₹ } 1,312,740 (1 + 2.1)$$

$$= \text{₹ } 4\text{M}$$

$$\text{Fixed Capital (FC)} = \text{PPC} (1 + f7) \text{ FC}$$

$$= \text{₹ } 4,069,494 (1 + 0.01)$$

$$= \text{₹ } 4.1\text{M}$$

D5.1 2 Working Capital (WC)

WC is taken as 5% of FC WC

$$= \text{₹ } 4,110,269 \times 5\%$$

$$= \text{₹ } 205,464$$

D5.3 Total Investment (TI) = FC + WC

$$\text{TI} = \text{₹ } 4,110,269 + \text{₹ } 205,464$$

$$= \text{₹ } 4.3\text{M}$$

D5.4 Variable Cost (VC)

Raw material cost ₹ 86,124

Water	₦ 91.5
Labour	₦ 404,961
Analyst cost	₦ 83,936
Electricity	₦ 4,627
Total	₦ 579,794

D5.5 Annual Production Cost (APC) = VC + FC

= ₦ 4,689,863

D5.6 Production Cost per Tonne (PCT) = APC/APR

1. APR (Annual Production Rate) = 8,453

PCT = ₦ 555

Revenue is generated only from desired products. In line with that the following economic evaluation was carried out.

APR = ₦ 697

2. Annual Sales (AS) = PCT X

SB (Saleable briquettes) = 9860

= ₦ 5.5M

D5.7 Annual Profit (AP) = AS –APC

= ₦ 5,471,739 - ₦ 4,689,863

= ₦ 781,876

1. Profit after Tax (PAT) = ₦ 625,541

$$\text{D5.8 Pay Back Period (PBP)} = \frac{TI}{PAT-D} \times 100$$

$$\text{Depreciation (D)} = \text{₦ } 237,606$$

$$\text{PBP} = 5 \text{ years}$$

$$\text{D5.9 Return on Investment (ROI)} = \frac{AP}{TI} \times 100$$

$$= 19\%$$

E TANNERY DERIVED BRIQUETTE PROJECT MARKET SURVEY QUESTIONNAIRE

E1 Questionnaire Design and Distribution

The survey was simply carried out by distribution of the Questionnaires to residents in Hayin Danyaro and Zango all within Sabo Gari Local Government Area, Kaduna State. They were given an orientation on the biomass fuel perspectives both at national and global level, the current Nigerian economic status, as well as the implication of long term production of on the economy. Secondary information was further obtained from a constructive review of critical Literature, newspapers and magazines that directly relates to the research in question.

The research questionnaire was designed to ask the respondents a summary of six questions that are believed to cover all the most likely impacts of briquette production in Nigeria. The questions are listed below.

- Q1.** What energy source do you use for your daily residence activities?
- Q2.** Where do you purchase the fuel?
- Q3.** What quantity of fuel is bought on monthly basis?
- Q4.** What is the amount of fuel used on a daily basis?
- Q5.** What is the average cooking time with the choice of energy source?

Q6. What is the monthly expenditure on fuel source?

About 100 Questionnaires were randomly distributed manually in 10 days to different households and institutions/Business. The respondents were given enough time (2 weeks) to study the research questions, so that appropriate suggestions could be made.

Fifteen respondents were invited for a demonstration on the use of briquette for cooking and parameters such as ignition time, burning rate, average cooking time and smoke emission were analysed. At the end questions were distributed to assess their opinion on the effectiveness of the briquette. The questions are listed below.

QA. Briquette takes less time to ignite compare to fire wood and charcoal.

QB. Briquette burns at a lesser rate compare to fire wood and charcoal.

QC. Briquette cooks faster compare to fire wood and charcoal.

QD. Would you use briquette to cook?

QE. What do you recommend for the improvement of the product?

Respondents were expected to state his/her level of agreement (Strongly Agree, Neutral, Agree, Disagree or Strongly Disagree) with each question. He has also been provided with an opportunity to add some critical comments and suggestions.

$$PAI = \frac{NAR}{NRQ} \times 100$$

$$PQR = \frac{NRQ}{NQA} \times 100$$

Where, PQR is the percentage of questionnaire responses, PAI is the percentage agreed impact,

NRQ is the number of recollected questionnaires while

NQA and NAR are the number of questionnaires administered and agreed responses respectively (Mohammed et al., 2013).

E2 QUESTIONNAIRE FOR PROJECT MARKET SURVEY

SECTION 1: Respondent Particulars

Name:.....

Gender:.....

Age:.....

District:.....

Occupation:.....

Highest formal qualification:.....

Total monthly income:.....

No of client/students:.....

Date of survey:.....

SECTION 2: Energy Sources

Qn1. Which of the following sources of energy do you use for cooking on a daily basis?

Tick appropriately

- Charcoal Wood Gas Kerosene
 Others, specify.....

(a) If you use charcoal or wood fuel, please state where these are obtained from.

.....

(b) How much of charcoal or wood do you use on a daily basis/monthly.

.....

(c) If the charcoal or wood fuel is bought from the market, please state at how much each of these is obtained.

.....

(d) What is the monthly/yearly expenditure on your choice of fuel.

.....

SECTION 3: Briquette Objectives

Qn2. Tick as appropriate on the effectiveness of briquette

	strongly agree	agree	neutral	disagree	strongly disagree
Briquettes take less time to ignite compare to charcoal and wood	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
B: cf	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Briquettes cook faster compare to charcoal and wood	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

SECTION 4: Respondents Comments

Qn3. Tick appropriately where necessary.

(i) Would you use briquettes for your daily residence activities.

Yes

No

(ii) What would you recommend for the improvement of the briquettes.

.....